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IN A [illegible]

BY

[illegible]

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[illegible]

CINDY

O WORKED UNSELFISHLY FOR FOUR YEARS

THAT I COULD COMPLETE MY EDUCATION

[illegible]

I would [illegible] encouragement [illegible] like to th[illegible] assistance from the ear[illegible] research [illegible] writing and review. I would [illegible] thank Dr. J.R. [illegible] H.T. Odum for many hour[illegible]ning discussions and [illegible] primary influence for the [illegible] research has come from [illegible] fessors, and I am deeply [illegible] their guidance thro[illegible] five years.

Special thanks are [illegible] of my co-worker[illegible] support and encouragement [illegible] needed. Witho[illegible] [illegible]'s cartographic and [illegible]ing ability, much of [illegible] been incomplete. Mr. Jerry Bowden contributed [illegible] effort so that input data and computer outputs were availabl[illegible] am grateful to them both for their hard work and good [illegible].

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Abstract of [illegible]
the University of Florida [illegible]
for the [illegible]

HYDROLO[illegible]
IN A [illegible]

By

[illegible]

[illegible]

[illegible]man: Dr. W.C. Huber
[illegible] Department: Environmental [illegible]

Techniques are presented to [illegible] logic land use interactions which [illegible] basin in order that environmental [illegible] off quantity and quality are char[illegible] and drainage patterns at several [illegible]ding the river basin, tributary watershed, [illegible] areas. [illegible] areas of runoff and nutrients are dis[illegible] transport mechanisms through the river [illegible].

Characteristics of the hydrologic [illegible] in the Kissimmee River Basin in Florida are view[illegible] storage and transport parameters related to the soil, [illegible] or stream components of the basin. The concept of [illegible] time, defined as the ratio of storage volume to outflow rate, is used to compare these various components. Detention time determines the hydrologic response of a reservoir storage unit, in terms of the potential for flood control. In addition, nutrient uptake rates on the land, in the soil, and in

[illegible]

[illegible] timate of storage are [illegible] of rainfall, land use, and drainage [illegible] rical and predicted future conditions are [illegible] areas which contribute large percentages of surface runoff [illegible] fied, as these have shorter retention times for nutrient up[illegible]

Potential nutrient loading rates are calculated for e[illegible] unit using measured concentrations of total phosphates and [illegible] runoff volumes. Higher concentrations and loading are [illegible] areas dominated by intense drainage. The drainage dens[illegible] measure of the total length of waterways per unit area, is [illegible] characterize each planning unit in terms of surface runoff [illegible] and nutrient loading. Detailed measurements of drainage [illegible] the lower basin are shown to be functions of land use, soil [illegible] and measurement technique.

Application of these management principles to the Kiss[illegible] River Basin indicates that lake and marsh areas have much hig[illegible] retention times than flows through drainage canals or the river. [illegible] order to control runoff volumes and nutrient loading from [illegible] it follows that drainage density should be kept to a minimum [illegible] possible. This can be accomplished through the use of mar[illegible] areas for on-site storage. Upstream lake retention times sho[illegible] maintained as high as possible through regulation schedules [illegible] there is little uptake potential in the river.

[illegible]

[illegible], variou[illegible] has [illegible] [illegible] to accelerate. Agricultu[illegible] [illegible]d water use have far-reaching effects [illegible] and environmental standpoints. The problem [illegible] determining an acceptable distribution of water quantity for all competing users is difficult in itself, but add to that the immense complexity of maintaining high levels of water quality at the same time and the problems seem insurmountable.

Environmental resource planners are being asked to solve these very problems in such a way that economic productivity from agricultural and urban pursuits, along with environmental quality, are both maintained. In addition, solutions should not favor any one group at the expense of another. There is hope that waste treatment and recycling will allow users of water, e.g., municipal, industrial, agricultural, recreational, and ecological, to exist harmoniously within the same region. The reality of the trade-offs which exist between continued economic productivity and environmental quality should indicate to what extent harmonious conditions are possible. There is no doubt that sacrifices will have to be made in one or both of these goals.

The problem to be investigated here revolves around the question of balancing agricultural and urban expansion with environmental

[illegible] the impact [illegible] developed.

[illegible]he predo[illegible] [illegible] which exist [illegible] land use regimes and which may result under some future conditions [illegible] more complex problem. Su[illegible] cause effect relationships are only now being addressed by environmental resource planners. It is first necessary to define indices of environmental quality which can be measured or predicted. [illegible] the environmental responses must be related to the land use [illegible] patterns so that a variety of interactions can be evaluated. Finally, the question of controls or constraints on these in[illegible] [illegible] be addressed so that trade offs between economic expansion and environmental quality can be quantified. The above concepts are [illegible] duced here and extended and quantified in later sections.

Traditional approaches to river basin studies have placed little emphasis on linkage mechanisms which relate land use and drainage conditions to resulting hydrologic and water quality responses in the watershed. Environmental indices which serve as useful measures of quality include the volume of surface runoff and streamflow, and associated nutrient concentrations or loadings which stimulate aquatic plant growth. Alterations in land use, drainage practices, and structural configurations can have significant impacts on these hydrologic and water quality measures.

[illegible]

[illegible] interactions between [illegible] in the watershed [illegible] ... physical processes [illegible], soil characteristics, [illegible], drainage intensity, land use, topography, and [illegible] are [illegible] considered because they all affect hydrologic and water quality response.

It is important to consider these interactions at several levels of detail in order to better understand the overall response of the watershed. Levels of resolution which are investigated [illegible] river basin, tributary systems (planning units), lake [illegible] [illegible]. Analyzing these different components allows [illegible] source areas of runoff and nutrients as well as [illegible] [illegible] mechanisms through the system.

Overview of the Research

[illegible] chapters serve as a literature review and [illegible] the [illegible] for more detailed presentations of theory and application. [illegible] II introduces general hydrologic principles, including a discussion [illegible] basin characteristics and the hydrologic effects of vegetation and land use. The chapter concludes with a section on watershed simulation models. Chapter III discusses water quality and ecological principles with emphasis on describing non-point nutrient sources and cycling in aquatic systems. A review of water quality models indicates the close relationship which exists between hydrologic and nutrient

[illegible]

[illegible]

[illegible] research [illegible] research [illegible] land use [illegible] quality responses [illegible] in is divided into sub [illegible] sheds or planning [illegible]. The upper portion of the basin consists of a chain of large [illegible] undergoing rapid [illegible]lization. The lower basin is undergoing [illegible]rsion from its natural state as a marsh and slough system to a [illegible] dominated by improved pasture with drainage canals. In addi[illegible] flood control project exists throughout the basin in the form [illegible] and channelization of the main river [illegible]. Water quality degradation in the form of excess nutrient load[illegible] the upper lakes and along the river channel has been [illegible] the last two decades. There is concern for protecting [illegible] quality, since the Kissimmee River Basin is the main inflow tributary to Lake Okeechobee, which provides water supply to all of South Florida and the Everglades.

Characteristics of the hydrologic and nutrient cycles in the Kissimmee River Basin provide a valuable conceptual framework for understanding the overall system dynamics. Each of these cycles is distinguished by a set of specific inflows, outflows, storages, and other losses which determine the response of a particular component of the system, e.g., soil, marsh, pasture, stream, lake, or planning

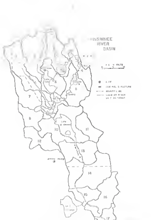


Figure 1.1 [illegible] Map of the Kissimmee [illegible]r Basin

[illegible]

[illegible] as the r[illegible] ratio [illegible] outflow [illegible] values of [illegible] large [illegible] rate [illegible]

[illegible] ous equati[illegible] stems [illegible] ndent [illegible] time for physical, biological, or chemical [illegible] mechanisms to operate. In general, the longer the retention time, the greater the uptake of nutrients either as plant biomass or as sediments.

The storage-treatment concept thus provides a [illegible] for investigating the response of various basin components [illegible] patterns of land use, drainage intensity, and nutrient [illegible] retention times are altered by various management practices [illegible] the system to act as a storage-treatment unit is also [illegible]

[illegible]

[illegible] lling is [illegible] hydrologic model has been developed [illegible] incorporates land [illegible] practices [illegible] based on determining [illegible] soil-land use [illegible] within each planning unit [illegible] providing an estimate of storage effects in the basin.

Hydrologic output [illegible] includes surface and [illegible] runoff values on a daily [illegible] routed through [illegible] system to Lake [illegible] land use [illegible] and predicted future land uses [illegible]

The information provided by such a model allows the [illegible] of storages and outflows from various land use and soil [illegible] Characteristic retention times are calculated under [illegible] of drainage and management for each component. Source areas [illegible] contribute large percentages of surface runoff can be identified [illegible] the effects of storage capacity on outflow rates from each planning unit can be investigated. In this way, the hydrologic model provides a characterization of runoff quantity as a function of land use patterns.

While the hydrologic model estimates source areas which contribute runoff volumes, non-point sources of nutrients are primarily a function of land use, with agricultural lands contributing the highest loads due to fertilization or cattle density. Water quality degradation, primarily

[illegible]

[illegible] used for [illegible] maximum storage capacity [illegible] during [illegible] used compared to natural conditions, causing a reduction [illegible] time for the rainfall which eventually flows to the [illegible] retention times contribute to an increase [illegible] loading from intensively drained areas for several [illegible] length of overland flow through vegetation is significantly [illegible] travel times through shallow groundwater regimes [illegible] are reduced, 3) [illegible] velocities in canals exceed [illegible] for physical uptake [illegible] vegetative surface area available for [illegible] uptake is reduced.

Detailed analyses of land use and drainage patterns along the lower river system indicate the importance of the drainage density index, defined as the total length of waterways divided by the [illegible] watershed area. Drainage density provides a useful general index of land use intensity, runoff volumes, and nutrient concentration associated with the various tributaries in the Kissimmee River basin. Drainage density is directly related to the average length of overland flow, soil moisture storage capacity, and surface runoff volumes via canals. In this respect, the index serves as an indicator of transport of runoff and nutrients for a particular land use type or for an entire planning unit.

[illegible] plain [illegible]

[illegible] ters and up[illegible]

Lake Kissimmee [illegible] channelized regime also assumes [illegible]istic retention [illegible] storage capacity. While seasonal stor[illegible] has been reduced, [illegible] flows have increased in the river, the annual retention ti[illegible] has probably been reduced due to channelization. However, the alter[illegible] of retention time and associated nutrient loading is more severe in the tributary drainage areas along the river. Thus, the primary cause of water quality degradation and increased flood flows may be due to upland drainage rather than floodplain channelization, but it is undeniable that both actions have served to decrease overall retention times in the basin.

Detailed analyses of the upper lake units indicate a similar problem to that which is occurring in the lower portions of the river, specifically, an excess of nutrients being transported to the receiving waters. Lake Tohopekaliga is the primary recipient of nutrients contained in the effluent from five sewage treatment plants which empty into the lake. Agricultural runoff provides an additional source. The lake has a large retention time and acts as a storage-treatment unit for these wastes, assimilating a large majority of nutrients as aquatic plant uptake or sediments before the water flows downstream in the chain of lakes. While it appears that uptake mechanisms are presently cleansing the water to a high degree within the

[illegible] the lake [illegible] type of analysis [illegible] the po[illegible]pected if nutrient [illegible] the lake is [illegible]d in the future.

The discussion thus far has emphasized the tributary and lake drainage system where runoff water travels overland, through canals, and via subsurface pathways. Only surface flows are assumed to contribute phosphorus concentrations of any significance due to the long retention times and uptake mechanisms in the soil. Actual concentrations associated from various land uses are reviewed in a later section. Evidence indicates that certain land uses provide uptake capacity for nutrient enriched water which flows from upstream areas.

In order to place the storage-treatment concept in proper perspective, a study of nutrient uptake in an actual marsh in the Kissimmee River Basin is presented. This provides a more detailed view of actual storage volumes, treatment rates, and retention times which occur in a storage-treatment unit of the basin. A marsh area in one of the planning units was selected because flow and nutrient data were available from an intensive field study conducted by the FCD. Predicted inflow runoff volumes from the remaining area of the planning unit were routed through the marsh area for several years of historical record (1967-1970). Stage-volume and stage-discharge curves were generated in order to characterize the storage-treatment and retention time parameters in the marsh. Results indicate that the average

[illegible] the expans[illegible]

[illegible] and [illegible]

[illegible] overall outcome. Thus [illegible]

[illegible] ted in the public areas before implementati[illegible]

...drologic C...

The ... is a concept ... and recharge of the earth ... Hydrology is defined in the following manner (Chow, 196?, p. ...):

> Hydrology is the science that treats of the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things.

As illustrated in Figure 2-1, the hydrologic cycle may be divided into three principal phases: 1) precipitation, 2) evaporation, and 3) surface and groundwater runoff. Quantities of water going through individual sequences of the cycle can be evaluated by a basic continuity or water-budget equation of the form

$$I - O = \Delta S \tag{2-1}$$

where

I = inflow of water per area per unit time

O = outflow of water per area per unit time, and

ΔS = change in storage volume associated with the given area per unit time

The hydrologic cycle has neither beginning nor end, as water evaporates from land and water surfaces to the atmosphere. The evaporated moisture eventually precipitates back to the earth

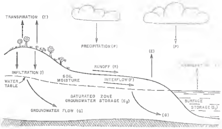


Figure 2.1 Components of the Hydrologic Cycle

[illegible] groundwater [illegible] tually re[illegible] streams or lakes fr[illegible] to complete the cycle.

The hydrologic c[illegible] of the various complicated processes of precipitation, evaporation, evapotranspiration, interception, infiltration, percolation, storage, and runoff. The basic theories and concepts underlying each of these processes is presented in detail in all of the following references: Chow (1964), DeWiest (1965), Eagleson (1970), Gray (1973), Linsley et al. (1975), and Viessman et al. (1972). A brief discussion of various components of the hydrologic cycle is presented below by considering the hydrologic equation.

The Hydrologic Equation

A schematic diagram of the hydrologic cycle for a region is presented in Figure 2.2, which can be readily translated into mathematical terms. Hydrologic variables P, E, T, R, G, and I, as defined in Figure 2.1, are subscripted with s or g to denote processes above or below ground. For example, R_g signifies groundwater flow which eventually reaches a surface stream, and E_s represents evaporation from surface water storage. The water budget applied to a region is a balance between inflows, outflows, and changes in storage. Figure 2.2 can be translated into the following mathematical statements:

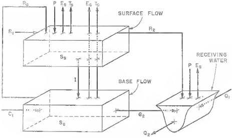


Figure 2.2 Water Budget of a Region
(Orlob *et al.*, 1967, p. 52)

(3) overall hydrologic budget (sum of equations 2.2 and 2.3)

$$P - (R_2 - R_1) - (E_s + E_g) - (T_s + T_g) - (G_2 - G_1)$$

$$= \Delta(S_s + S_g) \qquad (2.4)$$

where all values are in units of volume per unit time.

The hydrologic budget for a region can be simplified to

$$P - R - G - E - T = S \qquad (2.5)$$

where the various terms refer to total precipitation and net values of surface flow, groundwater flow, evaporation, transpiration, and storage, respectively, in units of volume per unit time.

The application of equation 2.5 to specific areas presents a difficult problem mainly due to the inability to estimate various terms in the equation. Precipitation is measured by rain gages located throughout an area. Point rainfall data are used to compute average depths over a specific area, and the density of the gage network significantly affects the value of the averages. Orographic effects and storm patterns also may alter the averaged results. Nonuniform distribution of gages can be accounted for in a weighting method developed by Thiessen (1911), whereby each gage is weighted by the ratio of the area surrounding the gage to the total area.

Surface flows can be measured by flow devices located in streams and rivers of the area. Estimates of surface runoff or

[illegible] recharge [illegible]

[illegible] and infiltrat[illegible] crude due to variations in drainage basin to[illegible] [illegible] and vegetation. Determination of the quantities of [illegible] [illegible]orated and transpired is also difficult because of the [illegible] [illegible] on similar factors. Most estimates of evapotranspiration [illegible] are obtained by using evaporation pans, energy budgets, mass transfer methods, or empirical relationships.

The Runoff Cycle

The runoff cycle is that portion of the hydrologic cycle between incident precipitation over land areas and subsequent discharge of this water through stream channels or evapotranspiration. There are three main routes of travel for water once it reaches the ground: overland flow, interflow, and groundwater flow. Overland flow, or surface runoff, is that water which travels over the ground surface to a channel. Interflow, or subsurface flow, infiltrates the soil surface and moves laterally through the upper soil layers until it enters a stream channel. It moves more slowly than surface runoff and reaches the stream later. Some precipitation may percolate downward until it reaches the water table and discharges into streams as groundwater flow or base flow. The

[illegible] flow is relatively constant [illegible]ly.

[illegible] the three components of flow [illegible] it has been customary to consider [illegible] divided into only two parts: direct runoff [illegible] The difference depends more on the time of arrival in the stream rather than on the path followed. The relative magnitude of the various components of the runoff cycle depends on the physical features and conditions of the drainage basin and on the characteristics of the rainfall.

A typical streamflow hydrograph resulting from an isolated period of rainfall consists of a rising limb, crest segment, and recession portion. The separation of a hydrograph into direct and groundwater runoff is somewhat arbitrary since the distinction between these two components is vague. Various graphical techniques exist for separating the base flow component. The most widely used procedure consists of extending the recession existing before the storm to a point under the peak of the hydrograph. From this point a straight line is drawn to the hydrograph at a point N days after the peak (ABC, Figure 2.3A). This procedure is arbitrary and no better than line AC, which is simply a straight line from the point of rise to the hydrograph N days after the peak. The difference in volume of base flow by these two methods is quite small. Another method is illustrated by line ADE (Figure 2.3A) in which the groundwater recession after the storm is projected back under the hydrograph to a point under the inflection of the falling limb. An

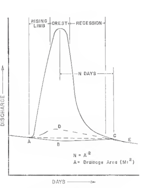


Figure 2 3A Streamflow Hydrograph Separation Techniques
(From Linsley *et al.* 1975, p 232)

[illegible]

The contribution to streamflow from a [illegible]ity and constant in time is depicted in Figure 2-3B. [illegible] precipitation is the only increment of streamflow during the [illegible] period of rainfall. The sum of interception, depression storages, and evaporation is referred to as surface retention. Available storages of surface retention and soil moisture are satisfied before appreciable surface runoff occurs. After a sufficiently long time, surface retention and soil moisture level off to constant values as determined by the loss to evapotranspiration. Water not retained as soil moisture either moves to the stream as interflow or penetrates the water table and may eventually reach the stream as groundwater. The rate of surface runoff approaches a relatively constant percentage of the rainfall rate.

The overall view of the runoff cycle presented in Figure 2-3B is a simplification of a very complex process. Variations in rainfall amount and intensity, soil characteristics, vegetative patterns, antecedent moisture, and topography all act to create a complex pattern of behavior. In an effort to describe the hydrologic response of a drainage basin, several conceptual views or models have been proposed to describe drainage basin dynamics. These are briefly described below.

Horton (1945) introduced the overland flow model (Figure 2-4A) which basically distinguished two main components of flow to the

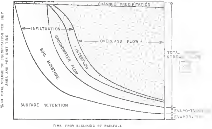


Figure 2.38 Components of the Runoff [illegible]
(Linsley, [illegible])

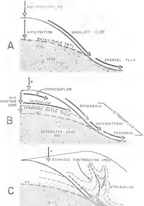


Figure 2 4 Conceptual Hydrologic Models
(Gregory and Walling 1973, p 28)

[illegible] would first be [illegible] surface runoff. [illegible] hydrograph separation techniques [illegible] base flow, and it treats much of the [illegible] contributing directly to the streamflow hydrograph.

Difficulties encountered in separating components of stream-flow hydrographs indicated that overland flow was not experienced in many drainage basins, and the observation of subsurface flow led to the suggestion of the throughflow model (Figure 2.4B). It has been proposed that throughflow, which occurs in the soil [illegible], and interflow, which occurs just above the saturated zone, are the most important modes of flow on hillsides in humid areas (Kirkby 19[illegible]).

More recently, awareness of the dynamic character of the drainage basin and its stream network, along with the fact that overland flow velocities far exceed those of throughflow, have prompted the development of the partial area and variable source area models of streamflow production (Figure 2.4C). These models view areas immediately adjacent to streams and lakes as being the regions most likely to contribute to runoff formation. In forested watersheds, Hewlett and Hibbert (1967) suggested that runoff production was achieved by expansion of saturated zones along the valley floors and over the lower portions of adjacent slopes. The contributing areas depend on rainfall, antecedent conditions, and basin characteristics.

[illegible]

[illegible] by all [illegible] components [illegible] spectrum of reservoir [illegible] and outflow rates [illegible] volume to outflow rate, i.e., retention time, [illegible] useful parameter to distinguish storage and flow capacities of various components in a river basin The reservoir concept can be applied and compared at various levels of resolution, e.g., river basin, tributary, lake, floodplain, or unit of land use In this way, it is possible to determine and quantify those regions most likely to contribute surface runoff.

From the above discussion, it is evident that the rainfall-runoff process is relatively complex, and that sophisticated techniques of analysis offer the most reliable method of predicting runoff from rainfall over a given drainage basin. The practice of estimating runoff as a fixed percentage of rainfall is commonly used for the design of urban storm-drainage facilities, a system dominated by impervious areas Computer simulation techniques have been devised to handle the more complex problem of predicting runoff and streamflow in a natural drainage basin. These methods will be reviewed in a later section First, it is necessary to describe the general and specific characteristics of drainage basins which relate to hydrologic responses in the watershed Also in this context, it is important to consider man-made changes in land use and drainage patterns and their relationship to watershed hydrology. These

[illegible] chapter, and extended and quanti [illegible] application to specific study [illegible]

[illegible] Characteristics

[illegible] drainage bas[illegible] area providing runoff to, and [illegible] part or all [illegible] flow of, the main stream and its tributaries. Drainage basin or watershed thus refers to the area enclosed by the boundaries of the surface and groundwater runoff system. The need to study the form and process relationships in the drainage basin derives from the function involved in the hydrologic cycle in conveying water from precipitation to its final destination as streamflow.

Measurement and quantitative description of the drainage basin were firmly established by Horton (1932, 1945) when he initially characterized drainage basins by morphologic, soil, geologic or structural, and vegetational factors. Langbein (1947) extended these ideas to include topographic characteristics which relate to drainage basin function. A drainage basin can be described by topographic parameters which include area and size, shape and pattern, relief and slope, and drainage density. A variety of interpretations are available in any of the following references: Strahler (1964), Leopold et al. (1964), and Gregory and Walling (1973).

Drainage basin area is difficult to correlate with catchment response due to nonuniform soil, vegetative, and topographic properties. High relief and slope indices tend to be associated

[illegible] been used [illegible] where [illegible] used [illegible] has a [illegible] characteristics and the index of streamflow. Glymph and Holtan (1969) illustrate different types of relationships which can result when mean annual runoff is related to drainage area (Figure 2.5). In humid areas such as Ohio, upland infiltration returns in part to downstream channels causing a gain in streamflow per unit area as basin size increases. In drier regions, runoff per unit area may be constant or decrease with increasing basin size.

Other indices of basin size have been used in relationships with watershed response. The length of the longest stream (L) was used by Merizman (1967) in a relation with mean annual discharge (Q) for watersheds in the eastern United States. Stream order, which measures the amount of branching within a basin, is of limited value in relation to measures of stream discharge unless the method of ordering is directly relevant to runoff production. A complete discussion of various methods for stream ordering is contained in Gregory and Walling (1973).

Basin relief, which refers to channel or valley slope, exercises an influence over peak runoff and sediment production in the basin. The significance of relief is difficult to ascertain because

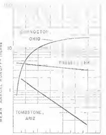


Figure 2.5. Mean Annual Runoff versus Drainage Area (Glymph and Holtan, 1969, p. 54).

[illegible] the [illegible] hydrograph [illegible] Figures [illegible] B, and C [illegible] (1965) The p[illegible] network also affects the hydrograph response [illegible] Figure 2.6D and E from Strahler (1964)

Many of the indices discussed above do not resp[illegible] dynamic character of the watershed because they express overall size, shape, or relief of the basin. It is now increasingly appreciated that only part of the basin actually produces runoff and sediment at a particular time. Therefore, of all topographic characteristics, perhaps drainage density is potentially the m[illegible] useful single index of drainage basin processes. The significance of drainage density stems from the facts that water and sediment yield are very much influenced by the length of water courses per unit area, and that it can be regarded as both an input or a response to input (output) to the basin.

Measurement of Drainage Density

Drainage density was defined by Horton (1932) as the length of streams per unit of drainage area, and he considered a range of drainage densities from 2.0 mi/sq mi for steep impervious areas to nearly zero in permeable basins with high infiltration rates.

More than 20 years of investigation from areas all over the world have shown a greater range in the values. Strahler (1957) described drainage density values less than 5.0 mi/sq mi as coarse, between 5.0 and 13.7 as medium, between 13.7 and 155.3 as fine, and

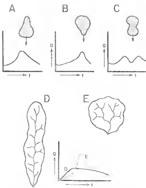


Figure 2.6 The Significance of Drainage Basin Shape (A, B, C) and Network Pattern (D, E) on Hydrograph Response (DeWiest, 1965, p. 72, and Strahler, 1964, p. 4-44)

[illegible] Values in the medium category [illegible] of the humid central and eastern [illegible] (the values have been measured [illegible] Smith, 1958).

[illegible] values are [illegible] to error because the densities most [illegible] from maps, aerial photographs or field surveys of [illegible] Horton (1945) originally suggested measuring the water courses shown as blue lines on U.S. Geological Survey 1:24,000 topographic maps, but a disadvantage of this method is that not all streams and valleys may be represented on the maps. Some workers have supplemented the network of blue lines with additional segments from the pattern contour crenulations (Carlston, 1963; Orsborn, 1970). Morisawa (1957) compared several methods for measuring drainage density and found that the blue line method differed significantly from other methods.

The drainage network varies according to the map scale and, in some cases, from one map edition to another. Giusti and Schneider (1962) compared maps of different dates and scales for the Piedmont region and demonstrated variations in drainage densities up to one order of magnitude for scales of 1:250,000 and 1:24,000.

Map convention, map scale, and method of determination of the drainage net must be considered to calculate drainage density values. Because these techniques are time-consuming, more rapid methods of calculation have been proposed. Carlston and Langbein (1960) proposed a rapid line intersection method which involves drawing a line of knownlength (L) on a contour map and counting

[illegible] intersect the line. An approxim-
[illegible] mi/sq mi as

$$D_d = 1.41\ [illegible]$$ (2.6)

[illegible] and infra-red photographs in order [illegible] density has also been utilized (McCoy, [illegible]).

Drainage Density Relationships

Drainage density occupies a central position in describing the drainage basin because it is closely related to other basin characteristics, as well as input to the basin and output from the basin. Attempts have been made to develop quantitative relationships of drainage density to climatic inputs and also to basin outputs.

Several useful relationships exist for describing stream areas, stream lengths, and stream numbers, all of which are important for understanding drainage density. The law of stream lengths (Horton, 1945) can be stated as

$$\frac{L_{u+r}}{L_u} = R_L^r \qquad (2.7)$$

where L_u is the mean length of channel of order u, R_L is the ratio of the lengths of different order, and r is a positive integer.

Another measure of network structure is the bifurcation ratio R_b,

$$R_b = \frac{N_u}{N_{u+1}} \qquad (2.8)$$

[illegible]

$$[illegible] \qquad (??)$$

where k is the order of the trunk segment.

Drainage density was defined by Horton [illegible] of total channel-segment lengths cumulated [illegible] basin to the basin area A_k, or

$$D_d = \frac{\sum_{i=1}^{k} \sum_{j=1}^{N_i} L_u}{A_k}$$

Horton (1945) combined the laws of stream nu[illegible] his definition of drainage density to yield

$$D_u = \frac{L_1 R_b^{u-1}}{A_u} \frac{R_{Lb}^{u} - 1}{R_{Lb} - 1} \qquad [illegible]$$

where D_u is the drainage density of an entire [illegible] order u, R_{Lb} is the ratio of R_L to R_b, and other terms are as defined previously. This equation combines all the geometric factors [illegible] determine the composition of the drainage net of a stream system into one expression.

The average length of overland flow L_g is approximately [illegible] the average distance between stream channels, which equals the reciprocal of D_d. When modified for the effect of land [illegible] slope, Horton (1945) expressed this as

[illegible]

[illegible] is the same [illegible] any group [illegible] In general, low drainage density is favored in regions of highly permeable soils, dense vegetative cover, and low relief. High drainage density is favored in regions of impermeable soils, sparse vegetation, and mountainous relief. Thus humid temperate areas tend to have lower densities compared to semi-arid regions. A comprehensive study of drainage density controls by Melton (1957) indicated a strong inverse relationship to the effective precipitation index of Thornthwaite (1948). Other independent variables such as infiltration capacity, vegetative cover, surface roughness, and runoff intensity were investigated. Of these, only surface roughness had no significant correlation with D_d. In another study, Carlston (1963) interpreted variations in drainage density according to terrain transmissivity.

The relationship of drainage density to basin output is perhaps most significant. The drainage network characterizes the infiltration capacity of soils and creates the density necessary for excess outflow from the basin. If channel patterns are constant, then discharge should be directly related to channel density because channel flow usually dominates the basin response. Runoff intensity depends to a large extent on drainage density (Melton, 1957). Mean annual flood is usually related to D_d in the form $Q_{2.33} \propto D_d^2$, where $Q_{2.33}$ is

[illegible] the dynamic changes of h_j [illegible] that total channel [illegible], [illegible] h_j, increases with [illegible] the form $Q = [illegible]$.

[illegible] drainage density [illegible] to be related to [illegible] of overland flow, soil moisture storage capacity, [illegible] as a general [illegible] drainage density can be associated [illegible] particular land use [illegible] the index are [illegible]. Thus, the [illegible] drainage density as a measure of land use intensity [illegible] storage concept which has already been [illegible].

[illegible] earlier, retention time also plays a key role in [illegible] nutrient loading and uptake rates. It follows that [illegible] density may serve as an indicator of nutrient levels [illegible] from a watershed because of the close relationships with retention time and land use. These effects are explored [illegible] in Chapter V. The next section discusses the effects of [illegible] and drainage practices on hydrologic response.

[illegible] associated land use patterns [illegible] [illegible]ibution of water on and under the [illegible] relationships between vegetation and hydrology summarized by Colman (1953, p. 69) in the following discussion:

> Despite their great range in form all types of vegetation share certain characteristics that are important in relation to water yield control. Every vegetative cover is made up of three parts: The canopy of living and dead stems and leaves that stands clear of the soil, the accumulation of dead and decaying plant remains that lies on or in the soil surface, and the living and dead roots and sub-surface stems that permeate the soil. The canopy above ground and the surface litter accumulation operate as barriers interposed between the atmosphere and the soil. They intercept precipitation, and thus temper the delivery of water to the soil. They insulate the soil, thus reducing the interchange of heat between soil and atmosphere, and they retard wind movement near the soil surface. Because both act as insulating materials they slow the evaporation of water from the soil. Their insulating effect, however, may be offset by loss of soil water through transpiration of the living parts of the canopy. At the soil surface vegetation obstructs the overland flow of water and the pickup and transport of soil material. This is accomplished by stems and litter accumulations that form miniature anchored dams and diversion walls, and by roots and decaying organic matter that mat the soil or bind it. Beneath the soil surface, to depths reached by roots, vegetation acts both directly and indirectly. Roots, by their growth and subsequent death and decay, permeate the soil with material that both binds it and aids the flow of water through it. Roots also absorb water

> [illegible] or ground parts of plants, [illegible] return of water to the [illegible] of vegetation that are b[illegible] [illegible] directly through the [illegible] the [illegible] rate for the activity [illegible] fungi, molds, and [illegible] organisms vegetation acts [illegible] living conditions, to most of the [illegible] soil. Some of them burrow in the soil [illegible] keeping it permeable to water [illegible] down organic matter and thus perform the same kind of function, while at the same time permeating the soil with the binding materials of their own bodies

The search for quantitative relationships between vegetation and hydrologic processes spans a broad spectrum of disciplines including forest hydrology, agricultural hydrology, botany, ecosystem management, water resources management, and land use planning. Research on forested and agricultural lands is at a relatively advanced stage compared to the analysis of natural marsh and swamp regions. Each of three land use types is discussed below with emphasis on presenting quantitative results where they exist. Nutrient and water quality considerations are deferred until Chapter III.

Forest Hydrology

One of the most widely quoted sources of information on forest hydrology is the International Symposium on Forest Hydrology (Sopper and Lull, 1967). Earlier qualitative treatments are presented by Kittredge (1948) and Colman (1953). Penman (1963) approaches the subject by considering the mechanisms of evapotranspiration as the dominant process linking vegetative type to hydrologic response. Pereira (1973) presents results from studies of tropical watersheds. Most of these sources include studies on small, well-monitored,

[illegible] change in [illegible] present [illegible] of small [illegible] fluence the response factors [illegible] impervious [illegible], average land slope, average annual [illegible], and land use. Forested watersheds are ranked according to mean precipitation (P), direct runoff or quick flow (V), and response factors $R_p = V/P$ and $R_y = V/(P-E)$ where E = evaporation. Hewlett and Helvey (1970) show an 11 percent increase in quick flow following forest clear-felling on a small Appalachian basin. Woodruff and Hewlett (1970) attempted to predict the average annual hydrologic response of ungaged watersheds in the East by regression against 15 basin parameters describing stream network, slope, and cover. The regression coefficients were non-significant indicating that response is controlled chiefly by soil storage and porous groundwater effects not included in the analysis.

Pereira (1967) discusses the effects of land use on water and energy budgets of tropical African watersheds. A series of experiments to study major land use problems were planned based on soil moisture studies. These included 1) replacement of mountain-protecting bamboo forests with softwood plantations, 2) replacement of rain forests with tea plantations, 3) control of clear-felled areas on steep slopes, and 4) control of overgrazed rangelands from erosion and floods.

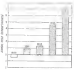
[illegible] by full canopies of bamboo, [illegible] ly equal. Replacement of rain [illegible] d in a two- to tenfold increase [illegible] were up to 50 times higher in tea [illegible] ginal forest. Controls on overgrazed ranchlands produced a doubling in penetration depth of water in the soil and a consequent reduction in surface runoff.

Douglass (1967) discusses the effects of species and arrangement of forests on evapotranspiration (ET) rates. Results indicate that pine forests consistently use more water, and from deeper depths, than shallower-rooted grasses, which signifies that moisture use is closely related to rooting depth. Length and density of forests are found to vary with distance from the water table. In addition, alterations in stand density generally tend to reduce ET and increase water yield (Figure 2.7A and B).

Lull and Sopper (1967) found, after analyzing 137 small watersheds in the Northeastern United States, that precipitation, percent forest cover, and maximum July temperature are the parameters which most influence annual and seasonal streamflows. They used multiple regression analyses to explain variation of flows among the watersheds.

Hibbert (1967) reports results for 39 studies on the effect of altering forest cover on water yield. Taken collectively, these studies reveal that forest reduction increases water yield, and that reforestation decreases water yield. The control watershed approach, one treated and one untreated, is used in most cases.

A



B

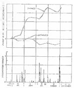


Figure 7 Change in Water Yield after Conversion of Hardwood to Grass (A), and Change in Soil Moisture under Thinned and Unthinned Loblolly Pine Plantation (B) (Douglass, 1967 p. 453)

[illegible]

[illegible] cutting experiment was [illegible]ted in 1939 and rep[illegible] in 1962 after regrowth. Streamflo[illegible]ses are almost identical (Figure [illegible].9A) and as the forest [illegible] following treatment, increases in streamflow decline, and the rate of decline is related to the rate of forest recovery as shown for several different studies in Figure 2.9B.

The above discussion indicates the complexities which surround forested watershed studies. Land cover, basin morphology, geology, and climate all interact simultaneously to produce the observed hydrologic response. While many of the above experiments on forested lands have produced only qualitative results, agricultural hydrology has made significant progress in obtaining quantitative relationships.

Hydrology of Agricultural Lands

The first real impetus for research on agricultural hydrology came from the U.S. Department of Agriculture (USDA) with the soil conservation movement of the 1930's. Research was aimed at determining the relative effectiveness of various farming practices and land uses in holding water on the land to reduce runoff and soil erosion. By 1964, studies had been completed on 900 small

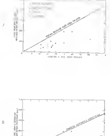
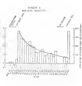


Figure 2-8 First-Year Streamflow Increases after Treatment versus Reduction of Forest Cover (A), and Showing Influence of Aspect (B) (Hibbert, 1967, p. 536).



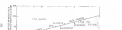


Figure 2.8 Streamflow Increases for Coweeta Watershed 13 Following Treatments (A), and Decrease in Water Yield versus Percentage of Area Reforested (A) (Hibbert, 1967, p. 538)

[illegible]

[illegible] al., 1962). [illegible] ranging from [illegible] 6 acres, were studied [illegible] as a control. [illegible] study began in 1938 with a series [illegible] treatments in the form of land use changes or alterations aimed at reducing runoff. Table 2 1 shows the details of the treatments and Table 2 2 shows the effects of the treatments after 10 years of application. All resulted in a decrease in water yield ranging from 15 to 44 percent, [illegible] greatest decrease being experienced in the watershed converted [illegible] forest cover.

Glymph and Holtan (1969), both with the Agricultural Research Service, review existing knowledge of land use effects on small agricultural watersheds. The general trend of results at three different latitudes is that runoff from small plots is inversely related to vegetative density and cultivation frequency (Figure 2-10). Studies at Hastings, Nebraska showed that peak runoff is greatest from straight-row cultivation and least for contoured watershed, and that conservation practices such as planned terraces, grassed waterways, and increased grassland help retain more precipitation on the land (Figure 2 11). The frequency of peak rates of runoff from watersheds of varying sizes and land uses are shown in Figure

Table 3.1 [illegible] and 1957 [illegible]
Study Watersheds

Watershed Item	172 1938	172 195[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Woodland	29.4	100.0	9.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rotation										
across slopes	0	0	47.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
contour strips	0	0	0	34.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Permanent pasture	50.5	0	31.1	49.5	[illegible]	[illegible]	[illegible]	26.8	[illegible]	[illegible]
Idle land	20.1	0	1.8	0	[illegible]	[illegible]	0	0	[illegible]	[illegible]
Miscellaneous	0	0	10.6	6.2	[illegible]	[illegible]	0.5	0	[illegible]	[illegible]
Area (acres)	43.6		75.6		23.0		74.[illegible]		[illegible]	

(From Harrold et [illegible]
p. 23).

[illegible]

[illegible]rsheds	[illegible]	[illegible]	[illegible]	[illegible]
Item				
Average runoff [illegible] (1957)				
Year	[illegible]	[illegible]	[illegible]	[illegible]46
Growing [illegible]	[illegible]	[illegible]	[illegible]	[illegible] 57
Dormant [illegible]	[illegible]	[illegible]	[illegible]	[illegible]9
Decrease in [illegible] (1938 19[illegible]7)				
Year	[illegible]	[illegible]	[illegible]	1 60
Growing [illegible]	[illegible]	[illegible]	[illegible]	1 00
Dormant [illegible]	[illegible]	[illegible]	[illegible]	0 60
Percent redu[illegible] (1938-1957)				
Year	[illegible]	[illegible]	[illegible]	1[illegible] 3[illegible]

[illegible] p. 9[illegible])

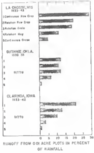
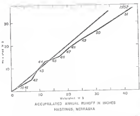


Figure 2.10 Effect of Farm Practices on Runoff Volumes (Glymph and Holtan, 1969, p. 46).



ACCUMULATED ANNUAL RUNOFF IN INCHES
HASTINGS, NEBRASKA

Figure 2 11 Comparison of Runoff from Conservation Measures W-5 and Straight-Row Farming, W-3 (Glymph and Holtan, 1960, p 49)

[illegible]

[illegible] The method involves the c[illegible] [illegible] depending upon the kind of soil, land use and c[illegible] type of land treatment. It provides for adjustments fo[illegible] levels of antecedent moisture as described by Ogrosky [illegible] (1964) Figure 2 14 shows the basic formula and family [illegible] for estimating runoff by this technique Table 2.3 pro[illegible] basis for selecting the proper curve number for a parti[illegible] cover complex

Interpreting the hydrologic performance of soil-cover com[illegible]plexes, considering the heterogeneous nature of watersheds, i[illegible] an easy task Besides variations in precipitation patterns and [illegible]rface features of watersheds as they increase in size, the prob[illegible]lem is further complicated by storage and movement of water in soils and underlying aquifers, and by natural gains and losses of water in stream channels

Glymph and Holtan (1969) illustrate different relationships which can result in humid areas, where some upland infiltration can return to downstream channels, compared to arid regions, where channels can absorb streamflow These dynamic storage effects

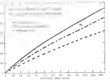


Figure 2.12 Land Use and Treatment Effect on 25-Year Runoff Frequencies (Glymph and Holtan, 1969, p. 51).

Figure 2.13 Results of Infiltration Studies on Various Soil Cover Complexes (Glymph and Holtan, 1969, p. 51).

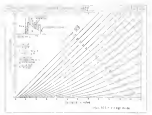


Figure 2.14 Soil Conservation Service Rainfall-Runoff Relationships (SCS, 1969, p. 10.21).

[illegible]

[illegible] or Cover	[illegible] or Practice	[illegible]	[illegible]	[illegible]logic [illegible] B	[illegible]	[illegible]
[illegible]	Straight row		[illegible]	86	91	[illegible]
[illegible]rops	Straight row	Poor	[illegible]	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and Terraced	Poor	61	72	79	82
Close-seeded legumes[1] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	59	75	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		–	59	74	82	86
Roads (dirt)[2]		–	72	82	87	89
(hard surface)[2]		–	74	84	90	92

(From SCS, 1969, p. 9.2)

[1] Close-drilled or broadcast.

[2] Including right-of-way

[illegible] and will [illegible] detail in [illegible] simulation models.

The USDA approach to watershed hydrology thus [illegible] to consider both land use or vegetative cover as well as soil storage in order to fully understand the response to changing land factors. The results of applying the hydrologic budget for calculating peak runoff rates from deep and shallow soils are shown in Figure 2.15. Vegetation significantly reduced the rate of runoff from the deep soils ($S_d \leq 0$ in), but had little effect on runoff from shallow soils. The influence of vegetation is closely related to cover density as well as to antecedent moisture conditions.

The effect of vegetation on overland flow rates has been studied by the Corps of Engineers (1954) using measured velocities to calculate Manning roughness coefficients in the Everglades region of South Florida. Manning's equation for channel flow is

$$v = \frac{1.5 R^{2/3} S_o^{1/2}}{n} \tag{2.13}$$

where v is velocity, n is Manning's roughness coefficient, R is the hydraulic radius, and S_o is the slope. Table 2.4 presents a list of n values for various cover regimes. Ogrosky and Mockus (1964) show graphs for the design of flow in grassed waterways for various vegetative retardances (Figure 2.16). In general, Manning's n is constant within a channel segment and increases

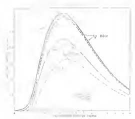


Figure 2.15 Effect of Vegetation and Soil Storage on Runoff Hydrographs (Overton and Holtan, 1969, p. 61)

[illegible]

[illegible]	[illegible]
[illegible] joints flush	[illegible]
[illegible] joints uneven	[illegible]
[illegible] ter	[illegible]
[illegible] steel troweled	[illegible]
[illegible] timber forms, unfi[illegible]	[illegible]
Untr[illegible] gunite	[illegible] to 0.017
Brickw[illegible] dressed masonry	[illegible].014
Rubble set in cement	0.017
Earth, smooth, no weeds	0.020
Earth, some stones and weeds	0.025
Natural river channels,	
Clean and straight	0.025–0.030
Winding, with pools and shoals	0.033–0.040
Very weedy, winding and overgrown	0.075–0.150

(From Henderson, 1966, [illegible])

Figure [illegible]. [illegible] in Manning's n in Grassed Channels, Where Curves A to E Show Declining Vegetative Retardance (Ogrosky and Mockus, 1964, p. 21-54).

[illegible]

[illegible]

[illegible] hydrologic [illegible] wetland [illegible] areas have only [illegible] been [illegible]. The [illegible] of flat land and surplus water has offered the oppor [illegible] the marshlands and transform them for crops and [illegible] usion exists concerning the function of marshlands [illegible] t as an obstacle to development. While marshes [illegible] ilar ecological associations of water loving plants, they may be sustained by entirely different physical causes of water [illegible]lus (Pereira, 1973).

In steep [illegible] ous country under high rainfall, marshes are found behind natural rock barriers, forming reservoirs which are drawn down by evaporation in dry weather to provide some degree of flood storage in the wet season. Drainage by cutting through the rock barrier destroys the reservoir storage capacity. Drainage by partial reduction of the water level and irrigation by intercepting the stream as it enters the marsh can provide an agricultural resource.

Where marshland is due to a loss of water velocity in a part of the flat streambed, as under the restricted drainage conditions in South Florida, dead plant material falling into shallow ponded water is not readily decomposed, and thick deposits of organic peats and muck soils gradually build up. A vast basin has emerged

[illegible] range, [illegible] r due [illegible] [illegible] [illegible] agricult[illegible] [illegible] of the drained [illegible] are being reflooded during portions of the year.

The removal of vegetation, to replace a swamp by an open water surface, was at one time believed to reduce evaporation, but studies by Linacre et al. (1970) have established by water and energy flux measurements that shading of the water surface by a cover of reeds can result in a reduction in water use.

Effects of marsh drainage on flood control are difficult to find in the literature. Studies of a long historical flow record in mountainous regions of Wales have confirmed that flooding is increasing due to both increased rainfall intensities and drainage of peat swamps. By plotting the flood peaks against drainage density (mi/sq mi), the authors obtained a logarithmic relationship (Rowe, Sloymaker, and Harding, 1966). A relationship developed for swamps in the Soviet Union also places significance on drainage density (D_d) and marsh area (M) as they affect surface runoff in the form

$$Q = (aD_d)/M^b \tag{2.54}$$

where a and b are constants (Chebotarev, 1966).

Results should be forthcoming on several research efforts in marsh and slough regions of South Florida. A recent study in the

[illegible]

[illegible] vessels and [illegible] on the water t[illegible] reducing water availability t[illegible] swamp. A reduction in annual [illegible] above-ground productivity and total biomass was reported for the area under the drained condition.

Barnes and Golden (1966) present an interesting relationship between the annual flood attenuation factor as it is affected by the percent area in lakes and swamps (Figure 2.18). The attenuation of floods is significantly increased for percentages less than 15 percent due to the loss in available storage capacity for slowing excess runoff rates.

Land Use and Retention Time

The previous discussion of vegetation and land use as they relate to soil storage, surface detention, evapotranspiration, infiltration, and surface runoff indicates the importance of land management techniques. The USDA method for computing surface runoff from various soil-cover complexes provides a first estimate of the range of soil storages and runoff rates to be expected from each type of cover. In general, those cover complexes with high soil storage capacity produce relatively lower runoff volumes than those with low soil storages. Results indicate that natural forested lands, marshes, and undrained pasture provide for considerable soil

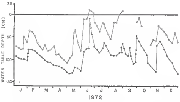


Figure 2.17 Effect of Canals on Groundwater Elevation (EPA, 1973,

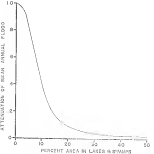


Figure 2.18 Attenuation of Mean Annual Flood by Lakes and Swamps (Barnes and Golden, 1966, p. 12).

[illegible]

and high ru[illegible].

The loca[illegible], soil a[illegible] detention, along with drainage density, to charact[illegible]-cover complexes fits equally well into the storage reservoir framework presented earlier. Characteristic retention times for each land use can be calculated based on soil storages and outflow rates determined by surface detention and drainage density. In addition, hydrologic simulation models, which are introduced below, can incorporate land use and drainage parameters to provide realistic hydrologic output under alternative management regimes. Component and basin retention times provide useful information for evaluation of management schemes.

Watershed Simulation Models

Due to the heterogeneous and dynamic nature of rainfall input, drainage basin characteristics, and land use changes, sophisticated computer simulation techniques have been developed to predict runoff and streamflow from a given watershed. The practice of estimating runoff as a fixed percentage of rainfall has been traditionally used in urban areas dominated by impervious areas. However, in drainage basins where vegetation and soil storage have significant effects on the hydrologic budget, simulation techniques offer the most reliable and accurate prediction tools.

[illegible]

[illegible] for the description of hydrologic [illegible] solution of two equations, the [illegible] for [illegible] uniform flow

$$[illegible] - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t} = 2.25\left(\frac{Q}{A}\right)^2 \frac{n^2}{R^{4/3}} \qquad (2.15)$$

[illegible] continuity

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q_L \qquad (2.16)$$

[illegible]

[illegible] slope

[illegible] slope

[illegible] depth

[illegible] dimension

[illegible]ity

[illegible] tational constant

t — time

Q — flow rate in x direction

A — cross-sectional area

n — Manning coefficient

R — hydraulic radius

q_L — lateral inflow per unit width

These two equations can be solved for v and y under certain condition using the method of characteristics or other numerical techniques for partial differential equations

For the case of steady, uniform flow, equation 2.15 can be reduced [illegible] the Manning equation, which incorporates a nonlinear relationship

[illegible]

[illegible] relationship is assumed [illegible] storage, then equation 2.18 may be further [illegible] to the Muskingum equation (McCarthy, 1938), for example [illegible] form

$$S = K[O + X(I-O)] \tag{2.17}$$

where

S = storage

O = outflow

I = inflow

K = travel time parameter

X = storage parameter

The solution procedure for this equation [illegible] Chapter V, where it forms the basis for flood routing [illegible].

The equation of continuity presented above can be simplified for an elemental control volume. Equation 2.16 transforms to

$$0 = I + \frac{\Delta S}{\Delta t} + q_L \Delta x \tag{2.18}$$

where ΔS represents a change in storage volume caused by inflows and outflows. In the simplifications leading to equations 2.17 or 2.18, variations of flow and storage with time are retained, but spatial variations are eliminated. The latter effects are incorporated in models by sequential application of the equations in a downstream direction for different spatial elements at each time step.

[illegible] budget of a region. [illegible] the Muskingum routing t[illegible] [illegible]oirs.

[illegible] of Available [illegible]

[illegible] numerous hydrologic models have been developed for [illegible] [illegible]ific needs. A representative spectrum of these models [illegible] briefly reviewed in this section with the ultimate intent [illegible] [illegible]velop a runoff model which directly incorporates drainage [illegible] [illegible] parameters. It will be shown later that these [illegible] [illegible] significant in characterizing the quantity and quality of [illegible] [illegible]rface runoff.

[illegible]tic hydrologic models basically describe the behavior [illegible] [illegible] a form of the equations of motion and continuity [illegible] [illegible]. Frequently, the models are structured to simulate or predict a streamflow value, hourly or daily, from given rainfalls within the drainage basin. The model is then calibrated by comparing results of the simulation with existing records. Once the model is adjusted to fit the known period of data, additional periods can be simulated for changing drainage basin characteristics or land use patterns. In this way the effect of proposed alterations can be evaluated in a reasonable fashion.

Soil storage dynamics are an integral part of the hydrologic cycle because surface runoff is largely dependent on the balance between infiltration and evapotranspiration rates. Much of the early

[illegible] takes [illegible]

$$f_t = f_c + (f_0 - f_c) [illegible] \quad [illegible]$$

[illegible]

f_t = [illegible] rate [illegible]

f_c = [illegible] infiltration rate

f_0 = initial infiltration rate

k = constant

t = time

Infiltration relationships have b[illegible] [illegible] [illegible] [illegible]lations to produce a variety of available wa[illegible] models. [illegible] [illegible] differ in terms of required input data, governing eq[illegible] [illegible] [illegible]put responses. Each model has been developed for [illegible] [illegible] emphasizing particular aspects of the hydrologic cycle in terms of storage or transport mechanisms. In addition, some are designed for simulating particular events in time, while others handle continuous input over a long period of time.

For simulation purposes in the Kissimmee River Basin, the hydrologic model must place strong emphasis on soil storage and evapotranspiration dynamics for determining areas of runoff contribution. The model must also handle spatial distributions of soil-land use types, and predict long-term seasonal responses as land use patterns change. Available models such as the Stanford Watershed Model (Crawford and Linsley, 1966) utilize concepts of soil moisture storage and

[illegible] groundwater flow, interflow, and over[illegible] [illegible] of an extensive array of input [illegible] places limits on its applicability [illegible] such as the Kissimmee River [illegible]

[illegible] models have been proposed by Betson (1964), Tennessee Valley Authority (1965), Dunne and Black (1970), and Lee and Delleur (1972). These models rely on the concepts of infiltration and soil storage, but they replace the classic overland flow regime of Horton by a varying response area. This saturated area appears along the banks and floodplains of streams and rivers, and is assumed to be the basic runoff generating mechanism. At this time, these models fail to properly account for the dynamic response area, because of dependence on antecedent moisture, rainfall intensity, topography, and soils.

The Storm Water Management Model (EPA, 1971) uses the Manning equation to generate overland flow and Horton's equation to determine infiltration rates. But the model was specifically designed for urban areas, and does not simulate continuous hydrologic response. Thus, its applicability to the Kissimmee River Basin is doubtful.

One additional model worthy of mention is the USDA Hydrograph Laboratory Model as discussed by Olymph, Holtan and England (1971). In the USDA model, infiltration is expressed as an exhaustion function of available soil moisture in the surface horizon of a soil (A-horizon) diminishing to a low, constant rate of intake associated with the impeding strata (B-horizon). The equation derived from small plots, small watersheds, and infiltrometer runs is

[illegible]

where

[illegible]

F_p [illegible]

f_c intake rate [illegible]

[illegible] coefficient [illegible]

As [illegible] depleted, the rate f approaches the minimum value, f_c. Soil Surveys of the Soil Conservation Service provide information on total moisture storage capacity of a soil, S, and for partitioning available moisture into pores drained by gravity, G, and pores drained by plants, AWC. The land use parameter, a, is a function of plant maturity ranging from 0.10 for fallow to 1.0 for sods and forests. Equation 2.20 is more directly related to soil and land use parameters than is Horton's equation 2.19. The drawback to the USDA infiltration approach is that detailed data or rates must be supplied for all soils, and calculations require less than hourly intervals.

Annual water yields computed by the model and compared to measured values for experimental watersheds in Hastings, Nebraska, and Coshocton, Ohio, are shown in Figure 2.19. It can be seen that predicted runoff is in reasonable agreement with measured values for these two watershed

The USDA model comes closest to meeting the stated requirements for a hydrologic model of the Kissimmee River Basin, except for its ability to simulate long-term seasonal effects with its infiltration equation. A model has been developed for this study which incorporates the spatial distribution of soil-land use complexes,

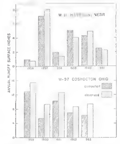


Figure 19 Annual Water Yields as Observed and as Computed by the USDA Hydrologic Model (Glymph and Holtan 1969, p. 66)

[illegible]

[illegible] Chapter V)

Outp [illegible] outflows fr[illegible] various soil [illegible] comple[illegible] [illegible] tic retention times are co[illegible] The model [illegible] terization of runoff quantity [illegible] function of [illegible] use, and drainage patterns. The reservoir storage [illegible] in the model at several levels of resolution, summing th[illegible] responses to yield the various tributary contributions, [illegible] to produce the overall basin response

[illegible]

[illegible]

[illegible] the gradual enrich[illegible] for the growth of [illegible] [illegible]ural process, but [illegible] man's activities. Nutrient[illegible] growth of [illegible], which can result in [illegible] [illegible]sirable changes [illegible]tem. Although exact [illegible] difficult to quantify [illegible] reasonable to assume [illegible] practices are a signifi[illegible] [illegible]ctor in the eutrophic[illegible] because they alter t[illegible] [illegible] and rate of nutrient transport from the landscape.

Mounting concern for maintaining water quality in lakes [illegible] streams has emphasized the need for quantitative information concerning nutrient budgets and loading rates in aquatic systems. It is generally agreed that the most desirable long-term management approach for receiving waters is to control the influx of nutrients, although there is considerable disagreement regarding the selection of nutrient sources which should be controlled, the method for control, and the benefit which is to be gained. Even though nutrient input reduction may not alone be sufficient to attain the desired level of water quality in all receiving waters, nutrient abatement

[illegible] Regar[illegible]

[illegible]

[illegible] and [illegible] parameters of water qu[illegible] [illegible] information [illegible] to provide some [illegible] guidelines. [illegible] next section discusses in more detail the quantification of [illegible]-point pollution sources.

Non-Point Pollution Sources

[illegible] (1967) suggested that if, at the time of spring overturn, concentrations of inorganic phosphorus (P) and nitrogen (N) exceeded 0.01 mg/l and 0.3 mg/l respectively, a lake may be expected to produce excessive growths of aquatic plants. Vollenweider (1968) concluded that the critical levels suggested by Sawyer applied to the conditions of lakes in central Europe.

Although these concentrations do provide useful target [illegible], it is difficult to relate reductions in nutrient input [illegible] lake nutrient concentrations. Tentative guidelines on specific loading rates are provided by Vollenweider (1968) for 30 lakes. [illegible] surface area of each lake is considered by expressing nutrient inflow as a specific loading rate ($g/m^2/yr$). Shannon and Brezonik (1972) conducted a similar analysis of nutrient loadings in 55 Florida lakes and these values are compared to Vollenweider's results in Table 3.4.

[illegible] Critical Loading Rates for Nitrogen and Phosphor[illegible]

Reference	Units	Permissible (g/m²) [illegible]	[illegible]	Dangerous [illegible]	[illegible]
Shannon & Brezonik (1972)	Volumetric (g/m^3-yr)	0.86	[illegible]	[illegible]	[illegible]
Ibid	Areal (g/m^2-[illegible])	[illegible]	[illegible]	[illegible]	[illegible]
Vollenweider (1968)[a]	Areal ([illegible])	[illegible]	[illegible]	[illegible]	[illegible]

[a]For lakes with mean d[illegible]

[illegible]

[illegible] d in the liter ture [illegible]

Several literature reviews [illegible] been [illegible] describe nutrient loadings from non-point sources [illegible] various land use types (Uttormark et al., 19[illegible]; Loehr, 19[illegible]). These loadings do not consider internal nutrient cycles or [illegible] transformations which may alter the availability of the n[illegible] for aquatic uptake

The characteristics and relative magnitude of non-point sources discharged to surface waters are compared by Loehr (19[illegible]). The non-point sources include precipitation, forested land run[illegible] agricultural runoff, cropland tile drainage, feedlot runoff, and urban runoff Available information on relative magnitudes of [illegible] non-point sources is summarized and the feasibility of controlling these sources is discussed

The impact of non-point sources on aquatic systems depends on intensity and yield factors as well as on the seasonal distributions of their contribution Knowledge of time changes in concentration, overland flow, and streamflow is essential for calculations of yield rates Comparison of non-point sources based solely on concentration units is difficult due to the flow-dependent, intermittent nature of the sources A better method of comparison is the use of the area yield rates such as quantity of source per unit area per

[illegible] loading [illegible]

[illegible]

Repo[illegible]ration and yield for total N and total P are pr[illegible] Figures 3.1 and 3.2 for various non-point sources (Loehr, 19[illegible]). The wide range in cropland P is due to the effect of soil erosion. Precipitation, forest land runoff, and surface irrigation return flow have comparable values. Subsurface irrigation return flow has higher N concentrations due to leaching from the soil. Animal feedlot runoff and manure seepage have characteristics that are many orders of magnitude greater than the other non-point sources.

Areal loading rates are compared in Figure 3.2 for the various non-point sources. The yields of total P from precipitation and rangeland are comparable as are the yields from land receiving manure, surface irrigation return flows, and urban land drainage. The yields of total P from forest land and cropland span a wide but comparable range, again probably due to erosion effects. The yields of N and P in animal feedlot runoff are again orders of magnitude greater than the other non-point sources.

Although these comparisons cover wide ranges and may be considered gross, they do permit an assessment of those sources that are controllable based on available technology. Actual decisions on controls will depend on the relative importance of respective sources in specific locations.

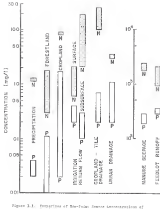


Figure 3.1. Comparison of Non-Point Source Concentrations of Total Nitrogen and Total Phosphorus (Loehr, 1974, p 1566).

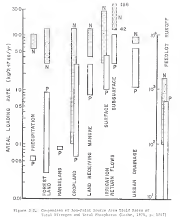


Figure 3.2. Comparison of Non-Point Source Area Yield Rates of Total Nitrogen and Total Phosphorus (Loehr, 1974, p. 1867)

[illegible] include [illegible] long as [illegible] generally [illegible] current [illegible] available [illegible].

[illegible]point sources that [illegible] require [illegible] control include cropland runoff and tile drainage, runoff from land receiving manure, and irrigation return flows. Controls should depend on the extent to which these sources adversely affect the quality of a particular receiving water. The basic control in this case is to avoid spreading fertilizers or manure at a time or location susceptible to rapid drainage.

Non-point sources that present the most problems include urban land runoff, manure seepage, and feedlot runoff. Collection and treatment of urban runoff prior to release is becoming increasingly feasible. Control of manure seepage and feedlot runoff is available through the use of retention ponds and grassed waterways.

Uttormark et al. (1974) present data from a broad spectrum of reported loading rates for agricultural lands, urban areas, forests, wetlands, groundwater, septic tanks, and precipitation. Armstrong et al. (1974) estimated that on the basis of surface runoff studies, agricultural lands could be further subdivided by flux coefficients as shown in Table 3.2. In comparison, the studies summarized by Uttormark et al. (1974) seem to indicate lower average rates for total N and total P from agricultural lands (see Table 3.3).

	Nitrogen loss, kg N/ha/yr		Phosphorus loss, kg-P/ha/yr	
	NO_3+NH_4	Total-N	Diss Inorg	Total-P
[illegible]	1.6	37.0	0.21	1.62
[illegible] crops	1.7	15.0	0.13	0.47
[illegible] meadow	2.3	2.5	0.22	0.24
[illegible] land	3.9	67.0	0.03	1.23

(From Armstrong et al., 197- p. 12).

[illegible]

Land use	[illegible] kg/ha/yr			Total [illegible] kg/ha/yr		
	High	Low	[illegible]	High	Low	[illegible]
Urban	5.0	1.0	[illegible]	10.0	2.5	[illegible]
Forests	3.0	0.5	1.5	5.0	1.0	[illegible]
Agricultural	10.0	1.0	5.0	10.0	2.0	5.[illegible]

	Diss inorg P kg/ha/yr			Total P kg/ha/yr		
	High	Low	Ave	High	Low	[illegible]
Urban	2.0	0.5	1.0	5.0	1.0	[illegible]
Forests	0.1	0.01	0.05	0.8	0.05	[illegible]
Agricultural	0.5	0.05	0.1	1.0	0.1	[illegible]

(From Uttormark *et al.* 1974, p. 108).

[illegible] sinks. [illegible] conditions increase [illegible] large o[illegible] soluble inorganic P [illegible] runoff pul[illegible] in the wet season.

Bentley (1969) presents r[illegible]sults which indicate that marsh[illegible] tend to accumulate nutrients during the growing season and release [illegible] during spring runoff. In addition, draining marshes may [illegible] [illegible] rease water quality by releasing large amounts of phosphorus [illegible] off. Based on these studies, it is estimated that nutrient runoff coefficients are approximately zero for wetlands. Further discussions on the effect of marshes on nutrient uptake are deferred until Chapter V.

Nutrient Cycling in Aquatic Ecosystems

The ecosystem is a basic functional unit of nature which includes both organisms and their nonliving environment, each interacting with the other and influencing each other's properties, and both necessary for the maintenance and development of the system (Odum, 1971). An ecosystem, then, may be viewed as a series of components, such as species populations, organic debris, available nutrients, primary and secondary minerals, and atmospheric gases, linked together by food webs, nutrient flow, and energy flow.

[illegible]

[illegible] connection to the surro[illegible] inputs and outputs in the f[illegible] f radiant [illegible] chemicals, or organic materials. These fl[illegible] ecosystem boundary by hydrologic, geological, or biological pr[illegible] (Bormann and Likens, 1967). Knowledge of input-output relati[illegible] is necessary in order to understand fully 1) energy and nutri[illegible] dynamics, 2) the comparative behavior of ecosystems, 3) the eff[illegible] of geological processes such as erosion, deposition, mass wasting and weathering on ecosystem dynamics, 4) the effect of hydrologic variations on ecosystem behavior, and 5) the effect of management practices on the structure and function of individual ecosystems (Bormann and Likens, 1969).

Measurement of these critical input-output relationships presents difficulties particularly in studies of nutrient cycles, which are strongly geared to the hydrologic cycle. Consequently, measurement of nutrient input and output requires simultaneous measurement of hydrologic input and output which may involve subsurface seepage, overland flow, or streamflow components.

Both the hydrologic and nutrient cycles can be described by specific inflows, outflows, storages, and other losses which determine the response of the particular lake, stream, or land use area. The retention time T has been introduced previously, and it serves as

[illegible] and nutrient dynamics. Poten-[illegible] length of time which water re-[illegible] ily available for physical, [illegible].

The [illegible] t uptake rates in a stream, [illegible] n of many complex, interacting [illegible] ll to quantify. However, there seems to be a greater potential for physical or chemical uptake, e.g., sedimentation or precipitation, when retention times are long. High flow velocities tend to aggravate these conditions. Biological uptake is also associated with long retention time, but the sea-[illegible] l effect of temperature on biological growth produces a greater [illegible] tial for uptake during warm months when more sunlight is [illegible] able for photosynthesis. Lake blooms of algae and excessive [illegible] tive density in marsh regions provide increased uptake capac-[illegible] for nutrients in the water.

Thus, the concepts of reservoir storage and treatment rates as a function of retention time and biological growth provide a useful framework for analyzing the complexities of hydrologic and nutrient mechanisms which are coupled in nature. The potential for nutrient loading from various land uses has been discussed. The potential for nutrient uptake in lakes and marshes, where T is long enough to provide some treatment, is introduced below and extended in Chapter V with applications to specific study areas.

[illegible]

[illegible] d-growth [illegible] the area [illegible] basement layer that prevents [illegible] by deep seepage. Streamflow [illegible] majority of [illegible] nutrient loss.

Six small watersheds [illegible] selected for the study ranging [illegible] area from 12 to 43 hectares [illegible] similar in altitude and veg[illegible] characteristics. At the base of each watershed, a concrete [illegible] constructed to allow the outflow of water to be measured and [illegible] and particulate loads sampled. Precipitation gages were placed [illegible] monitor the volume and nutrient concentration of incoming p[illegible].

The initial series of studies was designed to measure the [illegible] cesses occurring under undisturbed conditions. Over a five year [illegible] iod of time, annual precipitation ranged from 94.9 cm to 141.8 cm, averaging 123 cm, while calculated evapotranspiration (ET) varied only between 46.1 and 51.9 cm per year. Thus, the forest shows a high degree of homeostasis in water loss by ET and fluctuations in precipitation are reflected almost entirely in variations in total streamflow.

The analysis of nutrient balance required periodic measurements of concentrations of substances in precipitation and streamflow. The

[illegible] tionship [illegible] and [illegible] [illegible] high water [illegible] particulate losses [illegible] of minor importance in overall nutrient [illegible]. The [illegible] output was more strongly dependent on [illegible] of streamflow than on ionic concentration.

A nutrient budget of dissolved cations for the Hubbard Brook [illegible] system was determined from the difference between precipitation input and streamflow output by multiplying concentrations [illegible] water per hectare. The resulting budget is presented in [illegible]. The balance sheet of dissolved nutrients and the [illegible] particulate matter losses from a watershed with [illegible] (average 26 percent) attest to the great stability of the system. There is no question that the vegetation and organic [illegible] play a major role in determining chemical fractions lost either in solution or as particulate matter.

Following the study in the undisturbed condition, one of the watersheds was clear-cut in an experiment designed to evaluate the effects on streamflow and nutrient cycling. In the winter of 1965-1966, all woody vegetation was cut and left in place in watershed number 2. As expected, runoff increased partially due to the reduction of water loss to ET. Increased runoff amounted to 40 percent and contributed to an increase in outflow of dissolved and particulate

Table [illegible] [illegible] in an Undisturb[illegible] and 1967–1959

[illegible]	Pr[illegible] [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	151	153		171.8	[illegible]	—
[illegible]	[illegible]	[illegible]	[illegible]	1.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible] to nitrate [illegible] the [illegible] and Li[illegible]

[illegible] stu[illegible] [illegible] draining woodland [illegible] watersheds at [illegible]ton, [illegible], 1966 through 1969 (Taylor et al., 1971). Temporal variations [illegible] the nutrient concentrations were much smaller than streamflow changes, and no relationship was found between concentration and streamflow. Nutrient losses from farmland were significantly greater than those from woodland, with total N and P levels of 1.79 and 0.119 mg/l from farmland and 0.79 and 0.015 mg/l from woodland, respectively. The analysis of data shows that total nutrient losses cannot be calculated meaningfully unless both hydrologic and chemical data are available.

Nutrient Budgets in Lake Systems

Lake systems have provided a rich and diverse source for nutrient cycling studies. Lakes are inherently easier to study than larger watersheds or terrestrial ecosystems in terms of obtaining nutrient and hydrologic data necessary to define inputs and outputs. The various non-point sources for nutrient loading to lakes have been discussed in a previous section. Adequate data to predict lake response from large scale manipulations of nutrient budgets are still needed. Results from many ongoing research projects on lake management are yet to be finalized.

[illegible] vide [illegible] long-[illegible] ling [illegible] (mean [illegible] 33 m), it [illegible] rather frequently [illegible] the point that the hypolimnion [illegible] anaerobic, and the major portion of the phosphorus income (60-[illegible] percent) through treated sewage was diverted (Edmondson, 1972).

An interesting contrast to [illegible] Washington case is presented by Lake Sammamish which [illegible] the area of Lake Washington, [illegible] half as deep, flushes [illegible] rapidly, and received about [illegible] income of phosphorus before [illegible] was diverted. Its hypolimnion does go anaerobic [illegible]. However, the diversion from Lake Sammamish has had no [illegible] effect during five years on either P concentration or algal biomass (Welch et al., 1973).

The probable explanation for this lack of response is that the P income changes to Sammamish have occurred on the asymptote portion of a response curve that yields a much smaller change in algal biomass for a given increase in P income compared to Lake Washington. The dominant controlling mechanism of P concentrations is hypothesized to be large sediment exchanges. With a constant sediment release rate and a sedimentation rate controlled by the P concentration, only a slight reduction (7 percent) in concentration is predicted for the

[illegible]

[illegible] lake [illegible] by Dunst et al. [illegible] rep[illegible] available technol[illegible] [illegible] Approaches [illegible] 1) methods to li[illegible] and/or sed[illegible] in lakes, and 2) procedures to [illegible] sequences of lake aging. The former treats the underly[illegible] of lake problems, while the latter are cosmetic in nature.

Fertility and sedimentation in lakes can be limited by reducing the amount of nutrients and sediment that flow into them, mainly through wastewater treatment, nutrient diversion, land use practices, treatment of inflow, and other source modifications. In-lake schemes to accelerate nutrient outflow or prevent recycling include dredging, drawdown, nutrient inactivation/precipitation, dilution/flushing, biotic harvesting, selective discharge, sediment exposure and de[illegible]tion, and lake bottom sealing. In addition various physical, chemical, and biological approaches are available for managing lakes without treating the original source of degradation. These include aeration/circulation, water level fluctuation, use of biocides, pathogens, and many others.

There are many difficulties associated with remedial efforts. Lakes are complicated ecosystems and the ability to predict the response of lake systems to various treatments is so limited. In addition, each lake has its own unique set of characteristics, which frustrates attempts to transfer results from one lake to another that appears to

[illegible]

[illegible] which [illegible] trophica[illegible] in lak[illegible] have been introduced [illegible]cussions. While each lake and stream does represe[illegible] system, it has been possible to generalize some of the relationships on nutrient loading and cycling which have been developed in recent years. Many of these relationships have been formalized in terms of mathematical models of water quality processes in lake and river systems. A representative group of these models is reviewed in the next section.

Models of Water Quality and Ecological Processes

Water quality models are a relatively new development in the general area of environmental engineering. The original approach used in the solution of the BOD equation has been greatly expanded in recent years to consider the interrelationships between nutrient cycles, sediment loss, and consumer organisms in an overall ecological sense (Figure 3.3). Complex models have been developed which can be applied to both river and lake systems as long as necessary input data can be obtained or measured.

The basis for most water quality formulations is the principle of conservation of mass. In its simplest form, the mass balance equation becomes

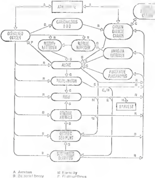


Figure 3.3 Water Quality and Ecological Interactions (Corps of Engineers, 1974, p. 20).

$$\frac{\partial}{\partial t} = \text{[illegible]} \qquad \text{[illegible]}$$

where

[illegible] t time t

If hydrodynamic [illegible] processes [illegible] factor, the equation describing the concentration distribution for a one-dimensional situation becomes

$$\frac{\partial C_i}{\partial t} - \frac{1}{A}\frac{\partial}{\partial x}\left(D_L A \frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial x}(UC_i) = W_i(x,t) - S_i(x,t) \qquad (3.2)$$

where

$C_i = C_i(x,t)$, concentration of pollutant i at point [illegible]

A = cross-sectional area

D_L = dispersion coefficient

U = advective flow velocity

W_i = sum of sources, related to C_i and other C_j

S_i = sum of sinks, related to C_i and other C_j

The above equation can be solved by numerical integration techniques in order to characterise the distribution of substances which are being modeled. A matrix of rate coefficients and transfer constants are required to describe the source/sink interactions between nutrient cycles and consumer organisms, as presented schematically in Figure 3.1.

The hydrologic inflows and outflows for a lake or river system must be continually updated in order that source/sink and advective terms in equation 3-2 can be calculated. Deep lakes can be idealized as a series of one-dimensional horizontal slices while a stream can be represented as a linear network of segments. Within each lake or river element the water is assumed to be fully mixed, while concentration

[illegible]

[illegible]

[illegible] models [illegible] in two general [illegible] [illegible] balance and hydr[illegible] equations which [illegible] [illegible] solution technique of these equations. In many [illegible] [illegible]ture of the equation determines to a large extent the [illegible] technique which must be used. But various assumptions are [illegible] employed to simplify equation 3.2 and the solution procedu[illegible] as assuming that steady state conditions apply, that dispe[illegible] advection are approximately constant in space and time, or th[illegible] sink term can be expressed as a first-order decay process.

A group of available water quality models are briefly [illegible] below in an effort to characterize water quality relationships [illegible] the Kissimmee River Basin. These models cover a wide spectrum of complexity, and simulate a variety of different pollutants. For the study area, total phosphorus is the primary nutrient of [illegible] and attention will be focused on techniques which incorporate it directly.

Early efforts to describe water quality interactions centered around the solution of the BOD equation. O'Connor et al. (1973) assume first-order decay and one-dimensional steady state conditions in simplifying equation 3-2 for BOD and dissolved oxygen deficit (DO). This formulation lays the groundwork for expansion of the model to incorporate the kinetics of consumer populations and their interaction with available nutrients. Unfortunately, the determination

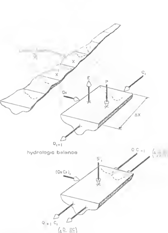


Figure 3.7 Segmented Stream System for Hydrologic and Water Quality Modeling (Corps of Engineers, 1974, p. 31).

e River Basin

The quality and ... form the basis of the ecological model developed ... (1972). This model is more complex than the previously ... steady state description because a system of mass balance equations is numerically integrated with respect to time. In this way, both spatial and temporal distributions are obtained for parameters of interest.

One advantage of this model is that hydrologic flows from reservoirs or river segments are calculated and used as input to the quality calculations. Figure 3 4 depicts the stream system which is represented by a linear network of volume elements. Each element is characterized by length, width, cross section, slope, and other hydraulic parameters. Advected inflow is represented by the QC terms and $(A \frac{D_L}{\Delta x} \frac{\partial C}{\partial x})$ represents transport due to longitudinal dispersion.

The model considers 17 different quality parameters along with interrelationships among them. For this reason, an extensive amount of input data utilizing a matrix of rate coefficients and transfer constants must be supplied for a particular study area. The model is able to simulate water quality, biological response, and nutrient cycles for a river basin which may include a series of streams, lakes, and reservoirs. However, data requirements for this formulation limit its applicability to well-monitored watersheds, thus eliminating its use for the Kissimmee River Basin.

[illegible] subsystem [illegible] consumers [illegible] nitrogen, and phosphorus.

The [illegible] equations provide [illegible] of changes in nutrient and [illegible] concentration in a completely mixed reservoir. Application of the model to lake systems requires information on specific growth rates, which is often lacking or difficult to [illegible]. Application to a river basin would require extensive hydrologic modification, and thus it was not considered for use in the [illegible] River Basin.

The models discussed above show the general types of formulations which are available to describe water quality and ecological interactions. Other groups have refined these relationships for specific study areas by emphasizing particular aspects of one cycle or process more than others. Huff et al. (1973) simulate the Lake Wingra ecosystem in Wisconsin by coupling hydrologic predictions from the Stanford Watershed Model (Crawford and Linsley, 1966) with dynamic equations relating nutrient loading and biotic response. The model is similar in some respects to the Rich Model, except that hydrologic inputs are directly incorporated.

Crawford and Donigan (1973) model the loss of pesticides from the land surface by simulating surface runoff, sediment loss, and various interactions between pesticides and the soil. They also use results from the Stanford Watershed Model, coupled with a sediment

[illegible]

[illegible] include [illegible] interactions tend to emphasize water quantity relationships, while the ecological models tend to emphasize biological and nutrient kinetics at the expense of hydrologic relationships. This observation is due primarily to the fact that models are developed for specific needs, and the original formulation lays the groundwork for all later modifications.

Most of the available aquatic models focus on processes which occur in the receiving lake or stream, assuming nutrient loading from point and non-point sources can be specified from other sources. This is the weakest link in these types of formulations, because in many cases non-point sources cannot be very well quantified as the previous discussion in this chapter indicated. Thus, one is left with a highly sophisticated tool for predicting water quality response in the receiving water, but very crude data on what is entering the system, especially from non-point sources.

From a management standpoint, the available models do not seem to provide the necessary relationships for determining 1) the influx of nutrients to a system and 2) the best control strategy for water quality improvement. Yet, it is agreed that quality will continue to degrade if the continuous influx of nutrients is excessive. Cause-effect relationships between nutrient sources and resulting water

[illegible]

[illegible] perhaps it [illegible] nutrient so[illegible] land use [illegible] tices and dr[illegible] [illegible] discharges. In this way, [illegible] a [illegible] the nutrients and possible strategies [illegible]

Concepts of [illegible]

The approach [illegible] in the Kissimmee River Basin must emphasize non point [illegible] control within the system rather than use a sophisticated water quality model where only crude [illegible] exist on loading and [illegible] rates, a simple technique has been [illegible] od which considers [illegible] components of the river basin as individual treatment units. Stream, lake, or marsh areas are all characterized by specific retention times which determine the potential for biological growth and nutrient uptake.

Reservoir treatment units are basically composed of inputs, storage, uptake, and outputs. If one assumes that inflows and outflows are constant, that the reservoir is completely mixed, and that uptake is a first-order reaction, then a mass balance of material through the reservoir, derived from equation 3.2, can be put in the form

$$V\frac{dC}{dt} = QC_i(t) - QC - kCV \qquad (3.3)$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] be shown in Chapter [illegible] equation 3 3 can be solved [illegible] certain conditions to prod[illegible] a simple relationship between inflow and outflow pollutant concentrations, dependent on the decay constant k and the characteristic retention time T of the reservoir. Because k is generally fixed for a particular component of the system, e g , lake or marsh, retention time serves as a quantifiable index for treatment potential. As retention times change with each treatment unit and with season of the year, general comparisons can be made.

[illegible] KISSIMMEE [illegible]

[illegible]

The Kissimmee River Basin [illegible] Florida between [illegible] Johns River Basin to the [illegible] and passes through [illegible] before emerging south [illegible] It then flows south [illegible] relatively [illegible] flood plain (see Figure [illegible]).

The basin can be conveniently [illegible] into upper and lower [illegible] includes 881,000 acres of land and 130,400 acr[illegible] while the lower river system includes 472,900 acre[illegible] 1,900 acres of surface water.

Parts of seven counties are within the bound[illegible] as shown in Figure 4.1. The area has been partitioned [illegible] areas based on the Soil Conservation Service d[illegible] units in the upper basin are designated as [illegible] the lower basin as river units. Much of the foll[illegible] is summarized from a report on the Kissimmee-Everglades [illegible] Soil Conservation Service (1973).

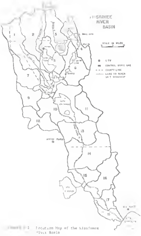


Figure 2-1 Location Map of the Kissimmee River Basin

[illegible]

[illegible] summer mont[illegible] temperatures [illegible] season, or [illegible]d between killing frosts, var[illegible] around Orlando to 365 days south of Lake Okeechob[illegible]

Rainfall over the basin varies seasonally [illegible] although the area has a fairly uniform average [illegible] approximately 52 inches with over 60 percent fallin[illegible] and October. The mean annual precipitation over the Ki[illegible] Everglades area is shown in Figure 4.2A. The distribut[illegible] age monthly rainfall and temperature in the northern and [illegible] part of the basin is shown in Figure 4.2B.

Physical Geography and Geology

The topography of the basin is dominated by the central ridg[e] of rolling hills along the western edge with elevation exceeding 100 feet above mean sea level (Figure 4.3). Drainage is principally into the thick, sandy soils. The area east of the ridge consists of a large, flat, swampy, pine forest interspersed with many shallow lakes with elevations between 50 and 100 feet mean sea level. The lowest elevations in the basin occur along the Kissimmee River flood plain marsh south to Lake Okeechobee. Numerous sloughs and small lakes drain the wet prairie adjacent to the narrow floodplain and ground water is near the surface over much of the area.

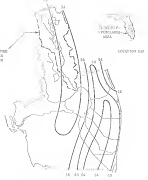
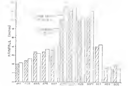
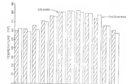


Figure 4 2A— Mean Annual Precipitation, Kissimmee-Everglades Area (SCS, 1973, p. 1-2).



AVERAGE MONTHLY RAINFALL



AVERAGE MONTHLY TEMPERATURE

Figure 4.2B Monthly Rainfall and Temperature in the Kissimmee River Basin.

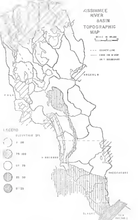


Figure 4 3 Topographic Map of the Kissimmee River Basin (SCS, 1973, p 1-3)

[illegible] The [illegible] prin[illegible] [illegible] west lo[illegible] forms a [illegible] primary [illegible] area fo[illegible] County, west o[illegible] the Kissimmee Rive[illegible]

A shallow aquif[illegible] in the Pleistocene deposits in the basin within 100 fe[illegible]rface. Recharge of nonartesian ground water is mostly from local [illegible]nfall. The groundwater table generally follows the topography of the land in flat areas, and may fluctuate up to five feet in elevation between wet and dry seasons of the year.

Water Resources

The Kissimmee River Basin contains vast quantities of fresh water available as ground water and as surface water in lakes and streams. The upper basin consists of many shallow lakes and several major streams draining both urban and agricultural areas. Reedy, Shingle, and Boggy are the more important creeks south of Orlando and Disney World (Figure 4.1). Recent studies indicate that Shingle Creek has the most severe water quality problems due to nutrient loading from several sewage treatment plants (Orange County, 1973).

The lakes of the upper basin provide more than 100 square miles of surface water area as shown in Table 4.1. Numerous smaller lakes scattered throughout the Kissimmee Valley provide additional storage capacity. Water quality problems are most noticeable in lake

[illegible] inee-
[illegible]

[illegible]	[illegible]
Okeechobee	[illegible]
Kissimmee	[illegible]
Istokpoga	[illegible]
Tohopekaliga	[illegible]
East Tohopekaliga	16
Weohyakapka	11
Hatchineha	10

[illegible]

[illegible]

Lakes Cypress [illegible] Kissimmee [illegible] improves

The lower basin [illegible] the Kissimmee [illegible] drainage areas convey an [illegible] annual runoff of 33 [illegible] Okeechobee. The average annual rainfall of 53 inches on Lake Okeechobee is approximately equal to the evaporation from the lake surface, and therefore most of the water supplied to the lakes comes from the Kissimmee River flow. The Kissimmee River drains mostly agricultural pasture, crops, citrus and natural slough systems. Water quality in the channelized river has become a serious problem in recent years based on extensive monitoring programs on the river as well as in Lake Okeechobee, which is considered to be in an early eutrophic condition (Joyner, 1971).

Lake Okeechobee, with over 700 square miles of surface area, is by far the largest lake in the region. It is regulated by control structures on outlet canals in order to maintain elevations between 15.5 and 17.5 feet (MSL). The stored water is used to irrigate farmland, supply the Everglades National Park with at least 315,000 acre-feet per year, and recharge the aquifers of Broward, Dade and Lee Counties for water supply purposes. The quality and quantity of water in Lake Okeechobee is thus an extremely important issue for all of South Florida.

[illegible]

[illegible] lowland areas. [illegible] distribution of five major [illegible] Kissimmee River [illegible]

Detailed soil [illegible] completed by the Soil Conservation Service for [illegible] and Okeechobee Counties (SCS, 1960, [illegible]), while the survey [illegible] County is nearing completion. These surveys provide a basis for estimating the location and extent of the most significant soil types within each lake or river planning unit for most portions of the basin.

Soils are grouped into larger units such as land capability classifications for various kinds of interpretations (SCS, 1961). This classification is based on the soil's capability to produce crops and pasture plants without long term deterioration. Subclasses are groups of capability units within classes that have the same kinds of limitations for agricultural use such as erosion (e), wetness and poor drainage (w), and root-zone problems (s). The approximate amounts of land in terms of capability classes and subclasses in the basin are listed in Table 4.2.

Vegetation

Natural vegetation in the basin is directly related to climate and soils. The vegetation map in Figure 4.5 shows the distribution of various types throughout the basin. The central ridge is dominated by forests of longleaf pine, _pinus palustris_, and turkey oak, _Quercus laevis_, with wire grass as a common ground cover. Many former areas of this type have been converted to citrus groves.

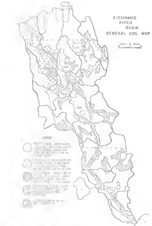


Figure [illegible] General Soil Map of the Kissimmee River Basin [illegible]

[illegible]

Water Profile Class (Land Capability Classes)	[illegible]	[illegible]
1 (I, II, III)	[illegible]	[illegible]
2 (IV)	[illegible]	[illegible]
3 (V, VI)	[illegible]	185.4
4 (VII, VIII)	[illegible]	[illegible]
Total	[illegible]	[illegible]

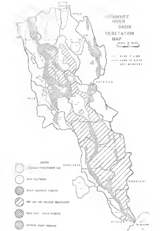


Figure 4.5 Vegetation Map of the Kissimmee River Basin

[illegible]

[illegible]

[illegible] leaf, [illegible] pond pin[illegible] Many [illegible] shrubs [illegible] small tre[illegible] form the understory, an[illegible] cypress swamps [illegible] wet prairies are [illegible] along drainage ways

A wide band of wet prairie grassland dominates border [illegible] of the large upper basin lakes and adjacent drainage areas along the Kissimmee floodplain Swamp forests, mostly hardwoods, border streams in northwestern Osceola County and line the narrow strip along the Kissimmee River floodplain Many former wet prairies have been drained and converted to improved pasture, especially along the river.

Fish and Wildlife Resources

The lakes furnish some of the finest fishing in Florida, especially for large-mouth bass, bluegill, black crappie and redear sunfish Lake Kissimmee and the Kissimmee River are rather distantly removed from population areas and receive less fishing pressure than the upper lakes. The river is productive from the standpoint of a bass fisher (GFC, 1957).

Waterfowl populations vary considerably from one lake to another and Lakes Kissimmee, Tohopekaliga, Cypress, Istokpoga and Hatchineha winter the bulk of the waterfowl in the basin Peak populations generally occur in January, and ringneck ducks tend to be the predomi[illegible] nant species. A comparison of the waterfowl population with the

[illegible]

Water and Land Resource Problems

[illegible]

The [illegible] soils of the [illegible] water hazards for agricultural [illegible] relative [illegible] soils are suitable for unimproved pasture [illegible] production, [illegible] require drainage for production of more intensive crops such as [illegible]ture, vegetables, or citrus. [illegible] the soils which are drained [illegible] excess water are used for improved pasture in the basin.

The natural surface removal rate of storm water is slow [illegible] although inundation is shallow, flooding is characterized by l[illegible] duration. Flooding causes damage to crops and improved pasture [illegible] affecting yields and creating delays in harvesting. Agricultural lands that suffer from flooding in the wet season of June to [illegible] are also affected by droughts during periods of low rainfall. A[illegible]ability of water is one of the most pressing problems affecting [illegible]cultural productivity.

Soil erosion and sedimentation are of minor importance in the basin due to the extremely flat topography. Areas of organic peat and muck which are drained for agriculture are subject to subsidence at a rate of about one foot in ten years. Drainage allows the organic soil to oxidize in an aerobic environment, and at present oxidation rates, the organic soils south of Lake Okeechobee are expected to be used [illegible] by 2020. This will present a problem because the area [illegible]

[illegible] fresh vegetables during the winter [illegible] beef cattle (SCS, 1973).

[illegible]

[illegible] the use of land for urban purposes [illegible] from the [illegible] conditions which contribute to agricultural [illegible]. Periods of heavy rainfall on flat, poorly drained urban areas cause flood damages. But many of the residential areas are poorly planned, with inadequate provisions for drainage or flood proofing. Developments have been allowed to build in flood-prone areas with poorly drained soils.

Planned developments, which involve large tracts of land in the basin, also create problems because increased runoff rates from [illegible] and paved areas cause additional flooding downstream of the development. Thus the problem of excess water is transferred off-site to a more vulnerable downstream user. On-site storage of excess runoff water appears to be one possible solution for the water problems inherently associated with rapid urban development.

Natural Land

Natural land in the basin includes forests, marshes, swamps, and grasslands which are generally uninfluenced by man's activities. The main problem with all of these areas is the question of preservation versus conversion to some other use, e.g., timber, improved pasture. In the past, marshes have been drained for improved pasture and forests have been cut over for short-term returns. The present environmental crisis has created a new awareness for the natural system, especially wetland areas with high biological productivity. Marsh and swamp

[illegible]

[illegible] ural, and [illegible]ation in [illegible] in the K[illegible]mee River Basin [illegible] achieved among these three i[illegible] large extent future levels of water availability, [illegible], flood damages, economic productivity, and a host of [illegible] related parameters.

Water Availability

Large quantities of surface and subsurface water are located in the basin, but rapidly increasing demands by agricultural, municipal, recreational, and industrial uses may create shortages in the future.

South of Lake Okeechobee the chloride and sulfate concentrations in the deep Floridan aquifer are too high for most uses. These concentrations are a result of salt water remaining in areas which were formerly inundated by the ocean. The Floridan aquifer is of high enough quality for municipal and agricultural uses in the Kissimmee River Basin.

Numerous lakes in the upper basin provide large amounts of surface storage. Lake Okeechobee and Lake Istokpoga are the major sources of surface water used by agriculture. Lake Okeechobee is also utilized to meet the needs of the Everglades National Park and to recharge shallow aquifers on the east and west coasts. In very dry years,

[illegible]

The [illegible] 1968 [illegible] Okeechobee [illegible], while south of Lake Okeechobee most [illegible] storage. According to Soil Conservation Service projections, irrigation water requirements are expected to increase along with agricultural expansion, especially in the Kissimmee Basin (SCS, 1973). Table 4.3 presents the projected irrigation requirements by county in the Kissimmee-Everglades area for 1968, 1980, and 2020. According to the SCS, organic soils south of Lake Okeechobee will be depleted to the point where farming operations are no longer feasible by 2020, and the Kissimmee Basin is projected to increase agricultural productivity to make up the difference. Irrigation requirements for Glades, Highlands, Okeechobee, Osceola and Polk Counties register large increases between 1980 and 2020 as shown in Table 4.3. Other counties south of Lake Okeechobee will undergo decreases in irrigation use as the organic soils are depleted.

The allocation of available water resources among competing users depends to a large extent on the land use changes which are projected to occur in the basin. Subsidence of the organic soils and the shift of agricultural activity to mineral soils of lower productivity requires increased acreages to attain projected levels of production.

By assuming that agricultural productivity will meet projected levels for the whole Kissimmee-Okeechobee area, the Kissimmee River Basin will come under increasing developmental pressure from agricultural

[illegible] Area – 1968, [illegible]

County	1968			198[illegible]			[illegible]		
	Crops	Pasture	Total	Crops	Pastu[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Broward	24.4	31.2	55.6	19.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Charlotte[1]	4.4	4.5	8.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Collier	21.4	4.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dade	41.4	6.3	[illegible]	[illegible]	[illegible]	[illegible]	31.[illegible]	[illegible]	[illegible]
Glades	13.6	33.2	[illegible]	[illegible]	[illegible]	[illegible]	95.[illegible]	[illegible]	[illegible]
Hendry	53.6	45.4	[illegible]	[illegible]	[illegible]	123.7	207.[illegible]	[illegible]	[illegible]
Highlands[1]	37.5	26.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lake[1]	3.5	——	[illegible]	[illegible]	——	[illegible]	[illegible]	[illegible]	[illegible]
Lee	17.6	5.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Martin	47.0	19.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Okeechobee[1]	3.1	14.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Orange[1]	10.7	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Osceola[1]	13.2	2.1	[illegible]	18.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Palm Beach	298.2	127.3	425.[illegible]	345.[illegible]	139.1	[illegible]	[illegible]	[illegible]	[illegible]
Polk[1]	40.2	1.5	41.7	51.7	[illegible]	54.5	57.9	14.5	[illegible]
St. Lucie[1]	52.3	9.4	61.7	59.4	18.[illegible]	77.9	90.7	38.8	[illegible]
Total	682.1	332.8	1014.9	800.1	4[illegible]2.1	1222.2	974.6	657.[illegible]	[illegible]

[1]Partial County

(From SCS, 1973[illegible]

[illegible]
available [illegible] users will [illegible] longer [illegible] maximization of [illegible] productivity [illegible] as the influence of land use changes on runoff, [illegible] flooding, and water quality, should be included in the overall [illegible] (see Chapter V).

Flood Control Plan

In October of 1956 the Corps of Engineers (COE) released a general design memorandum (GDM, 1956) on the Kissimmee River Basin. It cited the need for flood control and water conservation in the basin. Due to prolonged seasonal rainfalls, inadequate secondary drainage canals, and limited outlet capacity, large areas of the watershed were periodically flooded. Tropical hurricanes, which usually occur during the rainy season, also served to intensify the problems. Extensive and costly flooding occurred numerous times before the publication of the GDM, e.g., years 1945, 1947, 1948, 1951, and 1953, and the expanding agricultural economy in central Florida indicated that the flood damages would only increase in the future.

An overall plan proposed for flood control and water conservation in central and southern Florida was to be maintained by the Central and South Florida Flood Control District (FCD). This area comprises about 15,000 square miles and extends from Orlando to the

[illegible] groundwater table [illegible] rainfall.

The [illegible] structures was to [illegible] the following [illegible]

1. Remove [illegible] runoff from the lower basin waters [illegible]

2. Provide suff[illegible] capacity for the lakes in the [illegible] upper basin to limit the rise in [illegible] during the 10-year flood to two feet [illegible]

3. Provide suffi[illegible] regulation capacity for Lake Kissimmee to prevent maximum stages resulting from occurrence of the standard project storm from exceeding those stages that could be expected under existing conditions

4. Provide capacity in the Kissimmee River for the 10-year flood discharge from Lake Istokpoga.

5. Provide water control for the basin to maintain the lakes at desirable elevations, approximating the present mean stages.

6. Provide for navigation of the Kissimmee River and all lakes in the upper Kissimmee River Basin. Locks were to be provided at each control structure on the main waterway between East Lake Tohopekaliga and Lake Okeechobee.

7. Maintain levels in the lakes of the upper Kissimmee River Basin in consideration of recreational and fish and wildlife interests

[illegible] 11 canals, 16 water-control struc[illegible] [illegible] Secondary drainage structures were [illegible] [illegible] material would form spoil [illegible] designated S-65, 65A, 65B, 65C, 65 [illegible] structed in the Kissimmee River for water cont[illegible] (see Figure 4 1). Tieback levees would prevent flow fro[illegible] structures during floods greater than the design flood.

The Florida Game and Fresh Water Fish Commission (GFC) agreed that the above plan would meet the flood control, water control, and navigation requirements of the entire area under consideration. The GFC felt, however, that the plan would not provide optimum conditions for fish and wildlife. It therefore released a recommended program for the Kissimmee River Basin which would provide for fish and wildlife interests (GFC, 1957).

The GFC first presented a biological report on the basin. This was followed with an economic study of the value of fish and wildlife in the basin. The COE plan would result in minimum fluctuation in lakes in the Kissimmee River Basin, when compared to the natural seasonal fluctuation of up to 10 feet. Fish and wildlife benefits are increased by seasonal fluctuations according to the GFC and they indicated that fluctuations of about 6 feet would be satisfactory to fish and wildlife interests.

The GFC also conducted a study of the upper basin lakes to determine the effects of lake fluctuation and flood duration on the waterfowl in the area. The duration is a primary factor in determining

[illegible] riable [illegible] the GFC [illegible] adequate [illegible] regulation schedule was [illegible] of the [illegible] upon which waterfowl [illegible].

The GFC also expressed [illegible] in lake fluctuation [illegible] the fish resource. In [illegible] with fishing and other forms [illegible] water recreation, the Commission indicated a need for flexibility [illegible] operation of the locks along the canal or even self-service [illegible] by the public. [illegible] recommended that the natural channel [illegible] in the Kissimmee River be left open rather than sealed [illegible] were waterways very productive for fish populations.

In addition, the GFC concluded that the various control struc[illegible] on the river and their associated tieback levees should serve as water retention areas for the purpose of creating public lakes and wetland areas.

The flood control plan proposed by the COE, and somewhat amended by the GFC, was adopted and implemented in the early 1960's. The plan transformed the upper lakes into controlled reservoirs, and turned the Kissimmee floodplain into a channelized floodway governed by six control structures. With the coming of flood control to the upper lakes and lower basin, it was possible to transform upland marsh and

[illegible]

[illegible]

Land [illegible] r Basin has un[illegible] rapid [illegible] significant chang[illegible] 15 years. In the past activities in the upper part of [illegible] were dominated by urban interests, especially around the [illegible] area. Agricultural interests were involved in citrus on the [illegible] ridge, some improved pasture around the upper lakes, and large areas of unimproved pasture. By far the dominant natural category was freshwater marsh and swamp around the large lakes and adjacent to the Kissimmee floodplain. Figure 4.6 shows the general land use pattern which existed in 1958 based on analysis of aerial photographs of the basin. Areas were obtained [illegible] the county maps (1:126,720 scale).

Major shifts in land use have taken place following the con[illegible]tion of flood control structures and canals in the 1960's. Th[illegible] are depicted on Figure 4.7 which shows the 1972 land use pattern from aerial photographs. The most obvious shift is the conversion [illegible] 75 percent of the marsh and swamp areas to improved or unimproved pasture. Approximately 40 percent of former unimproved pasture has been brought into the improved pasture category through diking or drainage practices. Urban expansion is also evident primarily south of Orlando, around lake borders, and in the Disney World area of western Orange County

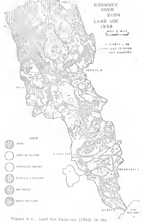


Figure 4.5. Land Use Patterns (1958) in the
Kissimmee River Basin

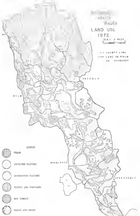


Figure 4.7. Land Use Patterns (1972) in the Kissimmee River Basin.

[illegible] and lake o[illegible] [illegible] over the [illegible] to descr[illegible] coverage [illegible] hydrologic, water quali[illegible] and economic pur[illegible]

[illegible]tailed land use changes for selected pl[illegible]ing units in [illegible] [illegible] and lower Kissimmee River Basin are shown in Figures 4 8A [illegible] [illegible] D. These figures depict the relative percent of land in the following categories: urban, cropland, improved pasture, unimproved pasture, citrus, forest, and marsh or swamp. An additional category of ditched improved pasture is distinguished in Chapter V. The 1958 and 1972 patterns are based on the aerial photographs, while the 2020 projections are from the SCS and represent an upper limit on agricultural activities in the basin. Such conditions may be constrained by runoff or water quality controls to protect overall basin integrity.

Land uses tend to compete for various soil types based on drainage and productivity potentials. Citrus usually establish on well-drained sandy soils which have no excessive flood hazard, while agricultural interests favor a wetter soil which contains clay and organic matter for maximum yields. Agricultural production can withstand some flooding in contrast to urban activities. When flood hazards are as extensive as in the Kissimmee River Basin, drainage of land becomes a common practice. As agricultural and urban production continue to expand on the limited soil resource, a point is reached where environmental degradation begins to dominate in the form of 1) increased off-site runoff, 2) increased downstream flooding in the wet

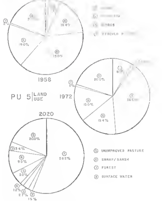


Figure 4.8A Detailed Land Use Changes (1958, 1972, 2020), Planning Unit 5.

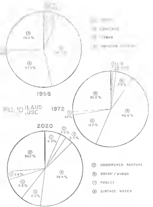


Figure 4.85 Detailed Land Use Changes (1958, 1972, 2020)
Planning Unit 10

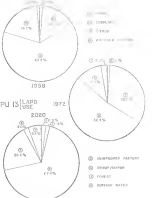


Figure 4 8C Detailed Land Use Changes (1958, 1972, 2020), Planning Unit 13

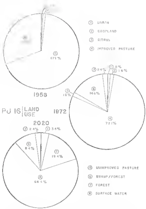


Figure 4.80 Detailed Land Use Changes (1958, 1972, 2020). Planning Unit 16.

[illegible]

[illegible] land use and drainage pr[illegible] created a series of effects [illegible] region's ability to cope with flood water[illegible] the observation of degrading water quality, as reported in [illegible] section, presents a possibly serious problem for lake Okeechobee.

Water Quality Monitoring in the Kissimmee River [illegible]

Water quality data for the Kissimmee Basin have been [illegible] in the river for the past several years, and in tributar[illegible] for the period September 1973 to October 1974. The original [illegible] program on the river was begun by the U S Geological Survey [illegible] has been continued and expanded by the Flood Control District (FCD).

While a large number of water quality parameters have been anal[illegible] under the monitoring system, the levels of nitrogen and phosphorus [illegible] of most direct concern because of their association with the eutrophication process. An analysis of available water quality data from the FCD indicates that total and inorganic phosphorus levels are the most responsive parameters, while no significant variation is observed for nitrogen levels. This can be explained by the assumption that phosphorus tends to be adsorbed by soil particles and is available for surface transport via runoff and erosion. On the other hand, most forms of nitrogen are soluble and can be leached from the soil or returned to the atmosphere, thus precluding any relationship with surface transport.

[illegible]

[illegible] and t[illegible] [illegible] samples were [illegible] [illegible] total P concentration as a function of sampling [illegible] lake and river segments depicts a very interesting [illegible] (Figure 4-10). [illegible] average concentrations are quite high in Lake Tohopekaliga, but decline rapidly before reaching Lake Cypress. Concentrations are further reduced to Lake Kissimmee at which point the levels indicate fairly good water quality. From the outlet of Lake Kissimmee to S65-C the levels remain fairly low, but increase rapidly between that point and S65-E.

The high levels of total P in Lake Tohopekaliga are primarily due to nutrient loading from treated sewage, and a complete analysis and budget are presented in a later section on the upper lakes. It appears that uptake mechanisms are presently cleansing the water to a high degree before it leaves Lake Tohopekaliga.

The water entering the Kissimmee River from S65 is of fairly good quality, but rapidly increasing concentrations south of S65-C indicate a rather serious situation regarding nutrient loading into Lake Okeechobee. The obvious question as to the cause of these increased concentrations can be answered by considering nutrient levels of water which enters laterally via tributary flow to the river.

Inflow tributaries which were sampled on a monthly basis did not yield any significant variation of total N from one location to the next, but total P levels showed a pronounced increase in wet season concentrations south of S65-C. Ice Cream and Pine Island Sloughs produced very low levels throughout the year (Figure 4-11), while Oak Creek

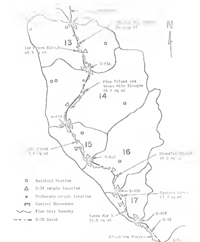


Figure 4 9 Tributary and Water Quality Sampling Locations, Lower Kissimmee River Basin

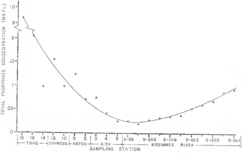


Figure 4.10 Total P Concentration as a Function of Sampling Location Kissimmee R...

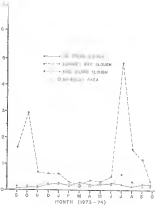


Figure 4 11: Total P Concentration in Tributary Inflows, Planning Units 13 and 14 of the Kissimmee River Basin

[illegible] and the Maple River yielded progressively [illegible] (Fig. 4.12). Blanket Bay in pool A [illegible] from Lake Kissimmee and Ice Cream [illegible] tration low.

It appears that the high phosphrous levels in the river are a direct result of tributary loading, especially south of S65-C. Later sections explore the effects of land use and drainage practices in each of these tributary areas as they relate to the measured nutrient concentrations.

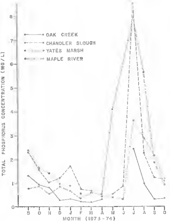


Figure 4.12 Total P Concentrations in Tributary Inflows Planning Units 15, 16, and 17 of the Kissimmee River Basin

CHAPTER V. LINKAGE MECHANISMS IN HYDROLOGIC-LAND USE ANALYSIS

Introduction to Storage-Control Concepts

[illegible]acteristics of the hydrologic and nutrient cycles [illegible] to the general framework of reservoir storage and [illegible] [illegible]drologic components in a river basin system are [illegible] [illegible] of specific inflows, outflows, storages, and losses [illegible] to the overall response. The retention time parameter [illegible] useful measure of reservoir storage and outflow, and [illegible] characterize various components of the hydrologic system [illegible] soil, marsh, pasture, lake, planning unit, or river.

Retention time also plays a key role in nutrient cycling as it relates to treatment rates for runoff on the land, in the soil, and in lakes or streams. In general, the longer the retention time, the greater the potential for nutrient uptake and/or deposition of sediments. Thus, water quality control through the system can be characterized by the length of time available for physical, biological and chemical uptake mechanisms.

Retention Time for Runoff Control

Surface and subsurface runoff volumes for a particular soil-land use pattern can thus be characterized according to retention time T. The value of T is defined as the ratio of storage volume to outflow runoff rate. Both soil moisture and surface components can be evaluated.

[illegible]

[illegible] stage-discharge relation [illegible] flow as a function of stage, [illegible] porous media.

At the surface, a definite breakpoint occurs for both stage-volume and discharge curves. Small increases in stage are associated with large changes in volume and outflow rates. The particular slope of the surface discharge curve depends on the land cover, as shown for unimproved and ditched improved pasture in Figure 5.2. These curves indicate the effect of drainage practices on increasing rates and volumes of surface runoff. Note also the decrease in surface soil moisture capacity as the water table is lowered from unimproved to ditched improved pasture.

The above concepts can be placed into a more useful context by considering the mechanisms of surface and subsurface runoff. It will be shown in the section on storage concepts that both surface and subsurface runoff rates can be directly related to the amount of reservoir surplus. This relation takes the general form of the continuity equation

$$\frac{dS}{dt} = I - O \tag{5.1}$$

If $I = 0$ and $O = kS$, then the solution to equation 5.1 is

$$\frac{S}{S_0} = e^{-kt} \tag{5.2}$$

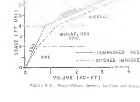


Figure 5.1. Stage-Volume Curves, Surface and Subsurface

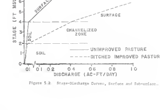


Figure 5.2 Stage-Discharge Curves, Surface and Subsurface

[illegible]

[illegible] for considering [illegible] and soil res[illegible] retention [illegible] ige values [illegible] ponents [illegible] basin. Fol[illegible] model, sp[illegible] and [illegible] range of [illegible] [illegible] shorter [illegible] be as [illegible] lower stor[illegible] index provide[illegible] managing and controlli[illegible] runoff in a [illegible] one obtains an estima[illegible] areas which [illegible] percentages of runoff.

<u>Retention Time for Water Quality [illegible]</u>

Based on the above concepts for runoff control, water qual[illegible] control can be placed into a similar con[illegible] by considering [illegible] time as an index of treatment potential. In the traditional [illegible] a treatment unit is composed of an input, uptake system, and [illegible] the treatment efficiency depends on [illegible] capacity, upt[illegible] and flow rates. The continuity [illegible] presented [illegible] water volumes also applies for water quality [illegible]

[illegible]

where

[illegible]

Figure [illegible] presents a [illegible]

Equation 5.3 is [illegible] and can be rearranged to [illegible]

[illegible]

where

$r = \frac{Q}{V} + k$

For the special case where [illegible] which can be solved to [illegible]

[illegible]

where

C = concentration of po[illegible]

C_o = initial concentration [illegible]

A plot of equation 5.5 [illegible] values of k. The expression [illegible] for concentration C, similar [illegible]

The above analysis [illegible] quality uptake rates [illegible]

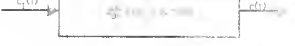


Figure 5.3 Schematic Water Quality [illegible]

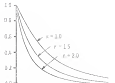


Figure [illegible] Typical First-Order Decay of Pollutant Concentration

[illegible]

different seasons for the [illegible]

The concepts of storage and [illegible] a unified methodology for considering [illegible] ponents [illegible] basin. Later sections extend and apply [illegible]tion [illegible] various levels of resolution for [illegible] and transport from the [illegible] through marshes, and eventually [illegible] of the river. The remainder of this chapter is divided into a [illegible]sion of storage concepts for hydrologic and water quality [illegible] dies, for runoff and nutrients. Following this, the transport section presents a detailed treatment of drainage density as a measure of on-site contributions to receiving water, flood routing through rivers, and routing through lakes and marshes. Both water quantity and quality relationships are considered throughout.

Storage Concepts

Hydrologic Analysis

Discussions in Chapter II indicated the types of watershed models which are available and have been applied to various drainage basins. [illegible] of these models addresses the problems associated with watersheds [illegible]nated by marsh and lake storage, extremely flat slopes, and long [illegible]

[illegible]

[illegible] emphasis on soil [illegible] changes over long periods of time. [illegible], the surplus water above the surface is [illegible] off at specified rates dependent on the vegetative [illegible] the rainy season lasts up to five months in these areas, the model must be capable of simulating long-term seasonal hydrologic response. During the dry season, streamflows are [illegible] largely by slow seepage of base flow from soil storage [illegible] relationships must also be included in the model. Thus, depressional watersheds are characterized by very slow vertical movements of [illegible] the water table as a function of rainfall. Lateral [illegible] determined by land use and soil storage, but is [illegible] due to poorly defined drainage paths.

In order to provide a realistic simulation for these depressional watersheds, a hydrologic model has been developed based on the daily water balance technique of Thornthwaite (1945). The procedure, discussed in detail in the next section, places primary emphasis on soil storage and potential evapotranspiration dynamics for long-term seasonal effects. This approach is ideally suited for modeling any depressional watershed.

The water balance

The regional hydrologic analysis is based on a water balance which consists of [illegible] and changes in storage for surface and

[illegible]

[illegible] characteristic [illegible] between precipitation (P) [illegible] transpiration (ET) [illegible]. Knowledge of the [illegible] between P and ET provides [illegible] periods of moisture surplus (S) and moisture deficit (D), which in turn provides data on irrigation requirements, surface runoff, groundwater recharge, and soil moisture storage.

Thornthwaite recognized that the actual water loss from vegetation varied with the amount of moisture in the soil, but it was not until 1955 that modifications were incorporated into the bookkeeping procedure to allow 1) variation in the available soil moisture from a few millimeters to over 300 mm, and 2) variation in the rate of water loss from the vegetated soil surface depending on the existing soil moisture content. These revisions make it possible to include different soils with different water holding capacities as well as different root zone depths of vegetation. The revised version was published along with detailed instructions on how to evaluate each component in the water balance (Thornthwaite and Mather, 1955).

The various terms and relationships involved in the water balance are shown in Figure 3.5. The budget can be run on a monthly, weekly or daily basis depending on the desired accuracy. Measured values of precipitation (P) and calculated potential evapotranspiration (PE), which

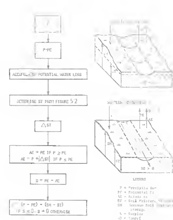


Figure 5 5 Schematic of the Water Balance

[illegible]

[illegible] to the [illegible] IF. A [illegible] [illegible] exceed [illegible]

[illegible]

$$[illegible] \qquad (5.?)$$

If the value of [illegible], [illegible] moisture storage. The [illegible] linear, because as the soil [illegible] plants are less able to [illegible] water via evapotranspiration due [illegible] capillary forces. Thornthwaite [illegible] that the actual amount [illegible] removal is proportional to [illegible] of soil moisture content [illegible] condition can be expressed [illegible] exponential relation of the form

$$ST = (SM)\, e^{-(DWL \times AWL)} \qquad [illegible]$$

where

DWL = depletion coefficient

AWL = accumulated water loss

Resulting curves for various levels of SM are plotted in Figure 5.6. Thus, for the case of curve A, if the accumulated water loss is [illegible] mm the resulting soil moisture retained (ST) is 62 mm. Because ST is less then SM, the AE term is no longer equal to PE for the case of negative (P-PE). Instead,

$$AE = P + |\Delta ST| \qquad (5.8)$$

where

$|\Delta ST|$ = available moisture which can be removed from the soil over one time step

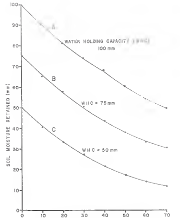


Figure 5.6 Soil Moisture Depletion Curves

[illegible]

[illegible]

[illegible] [illegible] ...imum of 39 mm in December [illegible] [illegible] ...ly. PE is at a minimum of 41 [illegible] [illegible] need increases rapidly to [illegible] peak [illegible] Excess precipitation (P-PE) [illegible] that a water [illegible] begins in November after [illegible] season of June [illegible] soil is recharged in the beginning of the year and a [illegible] surplus dominates until May when PE exceeds P by 20 mm. The [illegible] surplus during the year is 224 mm, which is available [illegible], compared to the total water deficit of 2 mm. This area [illegible] River Basin has more than adequate water surplus for [illegible] based on the 1958 land use patterns.

[illegible] figures refer to average rather than instantaneous conditions and cannot adequately represent brief periods of heavy rainfall or extended drought. Such local conditions can be better modelled using water balance computations on a daily basis.

Information provided by the water balance is useful for many reasons. First, it allows the determination of AE, the actual water loss from plant and soil surfaces, which is usually different from PE. Second, the difference between PE and AE provides a measure of moisture deficit which serves as the basis for calculating irrigation requirements of the extent of drought. Third, when water need is greater than P, that part of the demand met by stored soil moisture can be determined from the water balance. Fourth, when P exceeds water needs, the excess

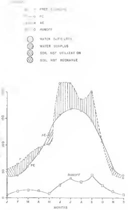


Figure 5.7 Seasonal Water Balance in the Kissimmee River Basin

[illegible] will [illegible]

[illegible] for [illegible] undergoing land [illegible] and veg[illegible] [illegible] urbanization. Drainage of land [illegible] soil storage, an increase in surface r[illegible]ff, and a decre[illegible] ground-[illegible]er levels, all of which can be quantified using the water bal[illegible] Increases in irrigation requirements can also be predicted based on increasing moisture deficits from drainage.

There are several shortcomings to the water balance procedure [illegible] iginally developed. Because of the extensive distribution of [illegible]-land use complexes which occur in a river basin, the technique [illegible] been computerized for rapid calculation on a daily basis. In addition, a method has been devised to calculate maximum soil moisture storages (SM) as a function of both soil type and land use.

Several additions have been incorporated into the water balance to better represent the hydrologic response. These are discussed in detail in the next section. Surplus runoff volumes calculated on a daily basis are constrained to flow at specified rates depending on the soil-cover complex. Estimates of baseflow are subtracted from soil storage on a daily basis. Finally, runoff contributions are summed for each planning unit and a flood routing option is available.

Description of the hydrologic-land use model

A hydrologic simulation model has been developed which uses the Thornthwaite water balance to calculate surface and subsurface runoff

[illegible] The mod 1, hereafter referred to [illegible] contributions from each soil-land [illegible] the total runoff from the water [illegible]

[illegible] t data to [illegible]] ude daily rainfall amounts [illegible] the simulation period Point estimates of rainfall [illegible] rain gages are distributed over the region using the [illegible] technique Specific areas of soil-land use complexes [illegible] comprise the watershed must also be supplied, in the form [illegible] (i,J,K) where i is the planning unit, J is the land use, and K is [illegible] soil type For the present scheme, there are 18 planning units or [illegible] atersheds in the basin, seven land use types, and four soil types

The SCS curve number method has been employed to calculate maximum [illegible] moisture storages SM(J,K) for each soil-land use complex The [illegible] ll-runoff relations depicted in Figure 2 14 for various curve [illegible] es depend on the following expression (SCS, 1969)

$$\frac{F}{S'} = \frac{Q}{P} \tag{5 9}$$

[illegible]

F [illegible] actual retention

S' [illegible] potential maximum retention ($S' \geq F$)

Q [illegible] t of runoff

P [illegible] potential maximum runoff = rainfall

[illegible] parameter S' is a constant for a particular storm because it is [illegible] maximum that can occur The actual retention F is a variable depending on the difference

$$F = P - Q \tag{5 10}$$

[illegible]

[illegible]

[illegible] I_a [illegible] The initial abstraction, I_a, [illegible] interception, infiltration, and surface storage, which occur [illegible] preceding runoff. A relation between I_a and S, which includes I_a, was developed by means of rainfall and runoff data from experimental small watersheds. The initial abstraction is brought into the relation by subtracting it from rainfall, thus yielding in place of equation 5.9

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad (5.13)$$

where $F \le S$, and $Q \le (P - I_a)$.

The equivalent of equation 5.12 becomes

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (5.14)$$

which is the rainfall-runoff relation with the initial abstraction taken into account, where

$$S = S' + I_a \qquad (5.15)$$

The empirical relation between I_a and S from experimental data is

$$I_a = 0.2S \qquad (5.16)$$

Substituting equation 5.16 into 5.14 yields the final equation

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (5.17)$$

[illegible]

$$SM(J,K) = \frac{1000}{CN(J,K)} - 10 \qquad (5.6)$$

[illegible] presents a representative range of [illegible] for the various soil land use complexes in the Kissimmee River Basin.

Once the water balance predicts surplus runoff volumes, it is necessary to provide detention storage constants to specify the [illegible] of overflow runoff from each land use type. The constants [illegible], defined as the percent of available surplus remaining on the land [illegible] day, vary from 60 percent to 90 percent for improved pasture and [illegible], respectively. These constants basically allow the surplus to become runoff at an exponential rate, or in direct proportion to the [illegible] which is available. The storage and outflow characteristics are used to calculate retention times of surface runoff from various land [illegible]. These results are discussed in the transport section.

In addition to the above information, RLAND requires further input data on the soil moisture regime, specifically, constants which describe the depletion curve due to ET in the water balance procedure. The constants are a function of soil and land use types, and basically describe the curves plotted in Figure 5-6. The depletion coefficients $DPL(I,K)$, are used in equation 5.7 to provide an estimate of the existing soil moisture as a function of the maximum level and the accumulated water loss $WL(I,J,K)$ in planning unit I.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]
[illegible]	85 00 1 76	[illegible] 1 76	[illegible] [illegible]	[illegible] 3 51	[illegible] [illegible]	[illegible] [illegible]	1.00 4.08
[illegible]	88 00 1 36	89 00 1.24	84 00 1 90	39.00 15 64	91 00 0.99	45 00 12 22	30 00 23 33
[illegible]	88 00 1 36	89.00 1.24	84 00 1.90	61.00 6 39	91 00 0.99	65.00 5.15	58 00 7.24

[a] Curve number (dimensionless)

[b] Maximum soil storage (in)

[illegible]

[illegible] gradient [illegible] a large v[illegible] following heavy rainfall [illegible] to the sat[illegible]. The rate of [illegible] is governed by particular [illegible] of the geology, topography, and soils of a region.

Base flow as a f[illegible] soil moisture storage has been specifically determined for [illegible] Kissimmee River Basin by Langbein (1955) and is depicted in Figure [illegible]. The relation was obtained through the [illegible] of hydrograph [illegible] for 15 years of streamflow data [illegible] the Kissimmee River. [illegible] flow is incorporated into HLAND by fitting an equation to [illegible] relation, and partitioning the [illegible] flows to each soil-land use complex in each planning unit. In this way, base flow is calculated as a function of soil moisture storage on a given day, and then subtracted from soil storage at the end of a day. If another type of base flow relation is preferred, it can easily be incorporated into HLAND.

Once surface and subsurface contributions of runoff are calculated for each soil-land use complex in a planning unit, these are summed up over all A(I,J,K) components to yield a total daily runoff from the planning unit. These values may be zero if soil moisture levels have been depleted to less than 30 percent of the maximum and no rainfall has occurred.

It should be mentioned that the model output is quite sensitive to at least three parameters: 1) the rainfall distribution, 2) the

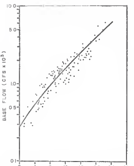


Figure 5.8 Relationship Between Storage and Base Flow (Langbein 1955, p. 547).

[illegible]

[illegible] superimposing land uses and soil types [illegible] soil storages from curve numbers provide [illegible] observed differences between measured and pr[illegible].

The flood routing section provides a [illegible] calibration phase of KLAND for a series of [illegible] basin. Following this, a complete range of [illegible] carried out for projected future land use p[illegible] in the basin. These results provide the [illegible] analysis in the Kissimmee River Basin, and provi[illegible] for further detailed studies along the river.

[illegible] retention times

The base flow relation for the Kissimmee River Basin [illegible] in Figure 5.8 was analyzed as a function of storage volume [illegible] to calculate retention time. Table 5.2 presents the results [illegible] storages range from 2 inches to 20 inches and produce [illegible] retention time of about 130 days for the basin. These levels [illegible] an upper limit for the control of runoff from the land under [illegible] conditions.

A similar analysis was carried out for surface runoff from [illegible] complexes. Detention storage constants CD [illegible] defined

[illegible] Retention Times

[illegible]	[illegible]	[illegible]	Retention Time (days)
[illegible]	[illegible]	[illegible] 667	151
[illegible]	1[illegible]	[illegible],333	158
[illegible]	3400	[illegible] 600	133
[illegible]	4600	60[illegible] 665	131
[illegible]	7600	75[illegible],333	99

[illegible]

[illegible] storage volume [illegible] can be [illegible] [illegible] distribution [illegible] [illegible] to route [illegible] within a planning [illegible] comparative results [illegible]

In general, [illegible] nutrient loading [illegible] relatively [illegible] contribute [illegible] surface [illegible] range of [illegible] 1 to 9.5 [illegible] more [illegible] of surface [illegible] studies [illegible] drainage areas [illegible] in later sections [illegible] and results are presented.

[illegible] Nutrient Loadings

Previous discussions on storage and control [illegible] the importance of retention time for both runoff and water [illegible]. Equations 5.2 and 5.5 are analogous in that both volume [illegible] trations obey exponential decay relationships for vario[illegible]. In order to utilize these relationships, decay co[illegible] times and initial conditions are required. While the

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	80	[illegible]	[illegible]
[illegible]	70	[illegible]	[illegible]
Ditched Improved Pasture	[illegible]	0.51	1 96
Other	[illegible]	0 69	1 44

[illegible]

[illegible] loadings on [illegible] take [illegible] measurements, [illegible]. A detailed review of [illegible] sources from [illegible] of land uses has been presented in Chapter III. Figures 3.1 and 3.2 summarize [illegible] of the problem, showing that nutrient loading rates for precipitation, forest land, and cropland take on a range of values depending on specific land management practices. Where animal [illegible] exceed normal levels as in animal feedlots, nutrient loading rates are several orders of magnitude larger. These values are reported on a per acre basis, and when averaged over an entire watershed, feedlot contributions may assume lower values compared to cropland or improved pasture receiving manure. The above results represent loads which are transported off-site.

Few studies have addressed the problem of primary nutrient sources on the land, mainly because it is difficult to generalize about the many interacting variables which influence the results. In attempting to relate fertilizer rates with observed nutrient transport, the transport mechanisms defy an accurate description. Cattle density or loading per animal represents a major source of nutrients in improved pasture areas. But grazing and migration patterns significantly influence the results, and transport mechanisms are difficult

[illegible]

[illegible] drainage [illegible] difficult [illegible] measurement [illegible] of land use, [illegible]

Given the [illegible] assumed that the relative [illegible] loading parameters were [illegible] and results are presented in [illegible] of drainage [illegible]

[illegible]

[illegible]

[illegible] as [illegible] the total [illegible] shed area [illegible] age basin [illegible] mics are [illegible] In this way, [illegible] associated water [illegible]

Factors [illegible] vegetative cover [illegible] permeable soil [illegible] densities [illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]10
[illegible]ved Fo[illegible]	10-30
[illegible] Drainage	15-50
[illegible]lot Runoff	50-500

[illegible]

[illegible] lands. S[illegible]inage a[illegible] developments and high inten[illegible] [illegible]oved pasture are usuall[illegible] extens[illegible] system of [illegible] canals, designed for water [illegible]rol. Thus, drainage density is tied closely to land use patter[illegible] and represents a useful index of land use intensity.

While other studies of drainage density have indicated the range in values to be expected from one watershed to another (Gregory and Walling, 1973), there has been very little work reported on variation within a watershed due to land use modifications. The Kissimmee River Basin has provided a useful study area because of the extremely flat slopes, generally uniform soil types, and the gradient of land use intensity which extends from Lake Kissimmee to Lake Okeechobee.

Relationship with land use

The initial survey of land use practice in the Kissimmee River Basin revealed a widespread shift to improved pasture condition from the original native range and marsh condition. As reported in the section on land use changes, the shift has been most pronounced in planning units 15 through 18, while 13 and 14 have remained in a relatively natural condition (see Figures 4 8A, B, C, and D). Land use data for the original survey were analyzed on county highway maps (scale 1:126,720).

[illegible]

[illegible] quadrangle [illegible] lled mar[illegible] distinguishing [illegible] categor[illegible] unditched [illegible] original [illegible] pasture and [illegible] pasture [illegible] major tributary systems depict not only [illegible] of improved pasture below PU 14, but [illegible] shift to ditched improved pasture in five of the [illegible]. The results of the land use survey al[illegible] accurately determining the characteri[illegible] patterns in each planning unit, with the [illegible] of the observed nutrient loading rates.

Measurement of Drainage Density

The measurement of D_d is a time-consuming effort b[illegible] aerial photographs must be thoroughly searched for the total length of drainage paths. Several techniques are available including 1) the blue line method on U.S. Geological Survey Topographic Maps (Horton, 1945), 2) the rapid line intersections method (Carlston and Langbein, 1960), and 3) the complete analysis of aerial photographs. The first two methods have the advantage of speed, but the third method is decidedly more accurate.

The detailed measurement of drainage lengths and areas on 1974 Mark Hurd aerial photographs was greatly simplified by the use of a Hewlett Packard Calculator (Model 9810) and D striker (Model 986 1)

Table 5.5. Land Use Anal[illegible]
(Ar[illegible])

Planning Unit & Watershed	Urban	Crop land	Improved Pasture	[illegible]	[illegible]	Forest	Marsh & Swamp	[illegible] Pastu[illegible]	[illegible]	[illegible]
(13) Ice Cream Slough	0 0	0 0	2.07 19.[illegible]	[illegible]	0 [illegible]	.93 [illegible]	1.01 [illegible]	0	[illegible]	[illegible]
(13) Blanket Bay Slough	0 0	0 0	1.12 22.4%	1.[illegible] 33.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(14) Pine-Island & Seven Mile Slough	0 0	0 0	3.14 16.7%	9.06 48.2%	[illegible]	.21 1.2%	5.[illegible] 29.7[illegible]	[illegible]	[illegible]	[illegible]
(15) Oak Creek	0 0	0 0	.91 45.7%	.04 2.0%	[illegible]	0 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(16) Chandler Slough	0 0	0 0	2.30 31.9%	1.39 19.3%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(16) Cypress Creek	0 0	0 0	3.63 22.1%	3.36 20.0%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(17) Yates Marsh	0 0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] resolution of 0.01 in. Areas are obtained [illegible] a resolution of 0.0001 in^2 [illegible] the 1:24,000 scale aerial photos [illegible] sample plots, in the shape of [illegible] diameters [illegible] are overlaid on each photograph [illegible] represents [illegible] to 25 percent of the total aerial [illegible] depending on the [illegible] of the watershed (see Table 5.5). [illegible] use pattern is determined by summing all the sample [illegible] each subwatershed. The digitizer technique thus [illegible] and accurate estimate of drainage lengths and land [illegible] aerial photographs.

[illegible] in the Kissimmee River Basin indicate the relative [illegible] techniques for selected subwatersheds. Table 5.6 [illegible] relatively natural areas the blue line map method [illegible] the value of D_d obtained from 1:24,000 aerial photographs. This is due to the fact that the quadrangle maps do not include all of the drainage lengths contained on the aerials. Conversely, the rapid line intersection method overestimates the value of D_d from the aerials. This method involves drawing a line of known length (L) in miles on a contour map and counting the number of streams (n) which intersect the line. D_d (mi/sq mi) is then approximated by

$$D_d = 1.41\ n/L \qquad (5.19)$$

Giusti and Schneider (1962) compared maps of different dates and scales for the Piedmont area, finding variation in D_d from 2.3 to 5.2 mi/sq mi and from 0.69 to 3.1 mi/sq mi at two different map scales. The values ranged from 0.23 to 5.3 mi/sq mi on map scales from 1:250,000 to

[illegible]

	[illegible]	[illegible]	[illegible]
[illegible]			
[illegible]	[illegible]	[illegible]	
Blue Line Map Method	[illegible]	[illegible]	
Aerial Photographs	[illegible]	[illegible]	1.82
Scale (1 126,720)			
County Road Maps	[illegible]	[illegible]	[illegible]
Scale (1 250,000)			
[illegible] Maps	[illegible]	[illegible]	[illegible]

[illegible] ning uni[illegible]

[illegible]

One of the main [illegible] map erro[illegible] the definitio[illegible] stream length as compared [illegible] associated aerial photograph. [illegible] ([illegible] 4) reviews the stan[illegible] for including perennial and intermittent [illegible] on topographic [illegible] of various United States agencies. The [illegible] Geological Survey [illegible] all of those streams up to 1000 ft [illegible] divide, and greater than 2000 ft in length for intermittent [illegible]. No length limit[illegible] are provided for perennial streams. Standards used by various agencies are presented in Table 5.7.

Map scale has a significant effect on the value of D_d in the [illegible] area. Table 5.6 shows that the larger the map scale, the lower the predicted level of D_d because drainage detail is sacrificed as map scale is increased. In addition, the county highway maps (1:126,720) do not give a proper indication of the differences in D_d for planning units along the river when compared to the 1:24,000 scale results. It [illegible] that the 1:24,000 scale aerial photographs provide the most accurate measure of the drainage network. Because 1972 Mark Hurd aerials [illegible] available for the entire Kissimmee River Basin, it was decided to [illegible] these to analyze D_d in detail. The aerials correspond to U. S. [illegible] Survey quadrangle maps of the region, and a list of these [illegible] map dates is presented in Table 5.8.

Table 5.7. Standards for [illegible]

Agency and Map [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Survey [illegible] 1:48,000 [illegible] 1:63,360	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Topographic [illegible] 1:25,000—1:50,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tennessee Valley Authority [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bureau of Land Management [illegible] 1:63,360 [illegible]	[illegible]	Established Channel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Service [illegible]	[illegible]	[illegible] Channel	[illegible]	—	[illegible]	[illegible]	[illegible]	—
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] of Stream	None [illegible] Intended Drainage Shown	[illegible]	[illegible]	[illegible]
[illegible] Survey [illegible]	[illegible]	[illegible]	No Limitation as to Length	1000 Feet on a Stream	—	[illegible]	[illegible]	[illegible]
[illegible] Navy [illegible]	As in Navigation	[illegible] Navigation Aid	No Limitation as to Length	—	[illegible]	[illegible]	[illegible]	[illegible]
Lake Survey Center Dept. of Commerce [illegible] [illegible] Scale [illegible]	All Perennial Streams	Any Permanent Channel	½ Inch (Well-Watered Areas)	To Stream Source	[illegible]	[illegible]	[illegible]	[illegible]

(After Drummond, [illegible] p. 35-36)

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]
Kissimmee	[illegible]		[illegible]
St Cloud N	[illegible]		[illegible]
Narcoossee	1953	[illegible]	[illegible]
Narcoossee SE	1953		[illegible]
Gum Lake	1959		[illegible]
Davenport	1953	[illegible]	[illegible]
Lake Tohopekaliga	1953		[illegible]
St Cloud S	1953	[illegible]	[illegible]
Ashton	1953	[illegible]	[illegible]
Holopaw	1953	[illegible]	[illegible]
Dundee	1953	[illegible]	[illegible]
Lake Hatchineha	1953		[illegible]
Cypress Lake	1953	[illegible]	[illegible]
Holopaw SW	1953		[illegible]
Holopaw SE	1953		[illegible]
Lake Wales	1952		[illegible]
Hesperides	1957		[illegible]
Lake Weohyakapka NE	1957		[illegible]
Lake Marian NW	1953		[illegible]
Lake Marian NE	1953		[illegible]
Babson Park	1952		[illegible]
Lake Weohyakapka	1952		[illegible]
Lake Weohyakapka SE	1952		[illegible]
Lake Marian SW	1953		[illegible]
Lake Marian SE	1953		[illegible]
Lake Arbuckle NE	1952		[illegible]
Fort Kissimmee NW	1952		[illegible]
Fort Kissimmee NE	1953		[illegible]
Fort Drum NW	1953		[illegible]
Lake Arbuckle SE	1952		[illegible]
Fort Kissimmee	1952		[illegible]
Fort Kissimmee SE	1953		[illegible]
Fort Drum SW	1953		[illegible]
Lorida	1952		[illegible]
Basinger NW	1953		[illegible]
Basinger	1953		[illegible]

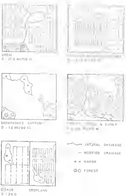
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]
[illegible] SW	[illegible]		[illegible] 16
[illegible]singer	[illegible]		[illegible],18
[illegible] Creek SW	[illegible]		[illegible],17
[illegible]	[illegible]		[illegible] 18
[illegible]nee NW	[illegible]		[illegible],18
[illegible]obee	[illegible]		18

[illegible]rresponding Mark Hurd aerial [illegible]graphs (19[illegible]-73 [illegible]ition) [illegible]ailable from Mark Hurd Aerial [illegible], Inc , 345 Pennsylvania [illegible]e Se , Minneapolis, Minn. 55[illegible]

[illegible] drainage p[illegible] [illegible] [illegible] [illegible] image [illegible] [illegible] channels, and [illegible] rd [illegible] [illegible] [illegible] and [illegible] [illegible] Figure 5.9

[illegible] results of analyzing the tributaries in the [illegible] [illegible]ee River are presented in Table 5.9. Figure 5-[illegible] [illegible] respective locations of these subwatershed areas. Man-made [illegible] [illegible]ies range from 18 to 33 mi/sq mi and include only those [illegible] [illegible] have been intensively ditched for improved pasture, citr[illegible] [illegible] or [illegible] use. The modified natural category includes natural [illegible], [illegible] and marsh areas which may have been partially channel[illegible] [illegible] connecting ponds or sloughs together. Natural densities rang[illegible] [illegible] to 2.3 mi/sq mi and include all areas of natural drainage [illegible] channel modifications.

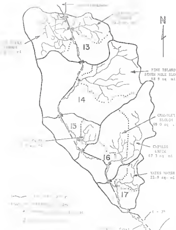
[illegible] [illegible]all average drainage densities combine the three drainage [illegible] into a single index for a given planning unit or slough system. [illegible] planning unit values range from 2.02 to 8.63 mi/sq mi while individual [illegible]ughs range from 1.49 to 9.23 mi/sq mi. Those areas dominated by ditched improved pasture tend to have the highest drainage densities, and these are schematically presented for each planning unit in Figures 5-11A through E. As one proceeds north from Lake Okeechobee, a definite break point occurs in the plot of total drainage length versus drainage



[illegible] Schematic of Land Use and Measured Drainage Density

Table 5.9 Drainage [illegible]

Planning Unit & Watershed	Drainage Characteristics (length (L) in mi, area (A) in sq mi, drainage density (D_d) [illegible])			[illegible]
	Manmade	Modified Natural	Natural	
(13) Ice Cream Slough	L = 5.21 A = 0.23 D_d = 22.65	L = 73.43 A = 60.11 D_d = 1.[illegible]	L = 11.5[illegible]	[illegible]
13	L = 290.64 A = 9.37 D_d = 31.02	L = 168.50 A = [illegible] D_d = 1.[illegible]	L = [illegible]	[illegible]
14	L = 408.03 A = 12.51 D_d = 32.62	L = [illegible] A = [illegible] D_d = 1.17	L = [illegible]	[illegible]
15	L = 205.83 A = 7.09 D_d = 29.04	L = [illegible] A = 60.65 D_d = 2.15	L = 36.36	[illegible]9
(16) Chandler Slough	L = 381.96 A = 14.49 D_d = 26.36	L = 45.73 A = 34.47 D_d = 2.15	L = 28.54	9.23
(16) Cypress Creek and Chandler Slough	L = 739.67 A = 34.25 D_d = 21.59	L = 101.50 A = 82.00 D_d = 1.84	L = 49.69	7.65
(17E) Yates Marsh	L = 135.10 A = 4.75 D_d = 28.44	L = 41.83 A = 38.82 D_d = 2.01	L = 36.59	4.89
(17W) Maple River	L = 94.25 A = 4.58 D_d = 20.60	L = 26.47 A = 20.83 D_d = 2.58	L = 1.75	7.90



Tributaries in the Lower Kissimmee River Basin

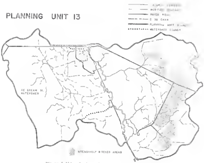


Figure 5 11A. Drainage Map of Planning Unit 13

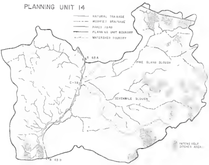


Figure 3.11B Drainage map of Planning Unit 14

PLANNING UNIT 15

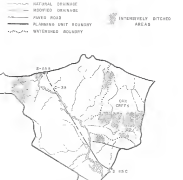


Figure 5 11C Drainage Map of Planning Unit 15

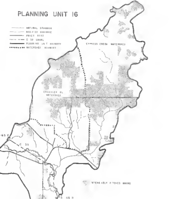


Figure 5.11D Drainage Map of Planning Unit 16

PLANNING UNIT 17

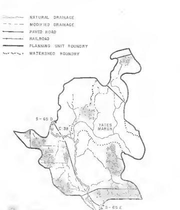


Figure 5 11E Drainage Map of Planning Unit 17

[illegible] th of S65 C have higher drainage [illegible] range from 3.33 mi/sq mi to [illegible]

[illegible] drainage density in the Kissimmee [illegible] other values reported for watersheds in the eastern United States where the average is 4.0 mi/sq mi. These are at the low end of the spectrum compared to drainage densities in arid regions, which range from 10 to 100 mi/sq mi (Figure 5.11).

Drainage density and hydrologic effects

Attempts have been made to relate the drainage density index to a variety of climatic inputs and basin outputs. The main thrust of these studies has been to look at streamflow response for a variety of watersheds with different soil, topographic, and drainage characteristics. Results usually relate some measure of average annual streamflow to D_d.

The main objective of this effort has been to describe and quantify various hydrologic-land use interactions which occur within a single river basin or watershed. There is a definite need to explain the distribution of effects which are observed at various locations within the river basin, such as surface runoff volumes and nutrient loading rates. If these can be related to various land use activities and drainage practices, then the question of control measures for these problems can be realistically addressed.

Results from the Kissimmee River Basin, with regard to hydrologic response predicted by HLAND, indicate the significance of land use and soil moisture capacity in determining runoff volumes. Figure 5.14

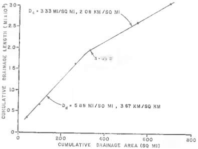


Figure 5 12 Drainage Length and Basin Area in the Kissimmee Rive

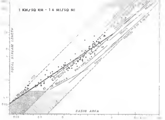


Figure 5.13 Drainage Length and Basin Area Relationships (Gregory and Walling, 1973, p. 273)

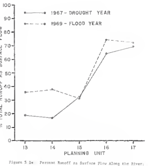


Figure 5 14 Percent Runoff as Surface Flow Along the River

[illegible]

[illegible] is due primarily [illegible] of the [illegible] If one [illegible] nt surface [illegible] against [illegible] indicates that they are approximately linearly related [illegible] Annual mean flood in m^3/sec/sq [illegible] watershed has been related to D_d (Figure 5.16) by other investigators. A data point for the Kissimmee River Basin has been inserted into the graph.

The above relationships are significant with regard to the [illegible] treatment concept presented earlier. Drainage density is [illegible] related to the average length of overland flow, channel [illegible] capacity, and surface runoff volume via canals. Thus the D_d index serves as an indicator of retention time T for particular land uses or planning units, where T is the ratio of storage capacity to outflow rate. Table 5.10 presents the planning unit surface retention times, determined from the land use pattern and detention storage constants CDET(J,K). Short retention times from intensively drained areas can contribute to an increase in surface runoff as well as nutrient loading, mainly because of the reduction in time necessary for physical, biological, and chemical uptake mechanisms to operate.

Drainage density and water quality effects

Previous discussions of water quality and non point source loading-

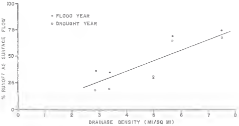


Figure 5.15 Percent Runoff as Surface Flow versus Drainage Density

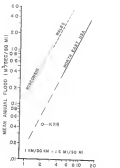


Figure 5.16 Mean Annual Flood versus Drainage Density
(Adapted from Gregory and Walling, 1973, ...)

[illegible] al Retention Times in [illegible] Planning Units

[illegible]	[illegible]	Retention Time (days)
[illegible]	[illegible]	3.66
[illegible]	[illegible]	5.53
[illegible]	[illegible]	4.16
[illegible]	[illegible]	2.19
[illegible]	[illegible]	2.24

[illegible] is an important parameter in determining [illegible]. Various ranges in values for nitrogen [illegible] reported in the literature under [illegible] conditions. However, the [illegible] reported rarely include any measure of [illegible] effect on potential for [illegible] transport. While [illegible], fertilizer rates, and grazing pastures have significant effects on nutrient source loadings in the Kissimmee River Basin, drainage density is by far one of the most representative indices of nutrient runoff off-site. Because of the overall uniform slope and character of agricultural land use in the lower basin, it was felt that drainage density might provide a valid general indicator of nutrient concentrations measured in the [illegible].

The relationship of D_d to average length of overland flow, along with nutrient loading potential, is analogous to the concept of sediment delivery ratios, defined as the fraction of gross erosion delivered to a stream (Midwest Research Institute, 1975). The basic approach considers the size of a unit watershed as a function of the potential for sediment delivery off-site. Figure 5.17 shows the sediment delivery ratio to be expected from various unit watershed sizes. The concept of drainage density can be placed into this same general framework, because the reciprocal of the square of D_d provides an estimate of the area of the unit watershed. The relationship between D_d and unit watershed area is schematically presented in Figure 5.18 for various land use types. Thus, the associated potential sediment

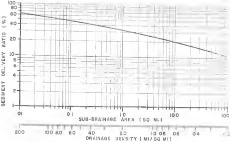


Figure 5.17 Sediment Delivery Ratio versus Drainage Density
(Adapted from Midwest Research Institute, 19

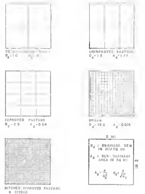


Figure 5.18 Schematic of Drainage Density and Watershed Area

[illegible]

[illegible] indicated [illegible] ation [illegible] time and space [illegible] tributing [illegible] were [illegible] ented in Fig [illegible] that both [illegible] verage [illegible] season (June [illegible] P [illegible] rapidly [illegible]

Based on the [illegible] level in each planning [illegible] concentrations [illegible] average and peak total [illegible] (1973) were plotted versus measured drainage densities. Although only a limited number of data points are available for the lower basin, positive correlations are obtained as shown in Figures 5.19 and 5.20. The importance of these relationships is not the actual measured values of D_d and associated P concentrations, but rather the fact that higher drainage densities tend to be associated with higher concentrations which are transported to the river.

With regard to nutrient loading rates, data on both hydrologic flows and nutrient concentrations must be available. While water quality monitoring has been extensive throughout the basin, the associated

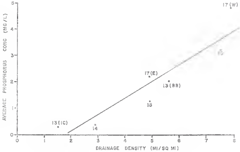


Figure 5.15 Average Total P Concentration versus Drainage Density

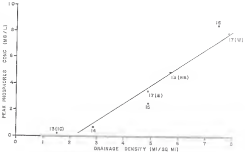


Figure 5 20. Peak Total P Concentration versus Drainage Density

[illegible]

[illegible] in the [illegible] d r noff volume [illegible] unit, a positi[illegible]n appears between measured total P concentration and the [illegible] surface runoff event which corresponds to the measurement (Figure 5 21) In general, the higher the surface runoff, the higher the concentration of total P which is transpor c! via overland flow and tributary to the river Thus, the phenomenon of dilution by increasing volumes of water is masked by more rapidly increasing volumes of nutrients transported in the runoff. Below 565 C, loading rates increase more rapidly due to higher surface runoff volumes and higher nutrient concentrations, combining to yield the nutrient flux into the river.

Nutrient loading rates are plotted against D_d and the resulting exponential relationship is presented in Figure 5.22, which can be explained by considering that higher drainage densities yield higher runoff rates and higher nutrient concentrations. Together, these produce a multiplicative effect on nutrient delivery rates. The range of nutrient delivery rates from 0.01 to 0.45 kg/ac/yr compares favorably with values reported by Uttormark et al. (1974) for similar types of land use (Table 3 3).

One other study has indicated similar relationships between nutrient loading of total P and drainage density in Canadian watersheds (Kirchner,

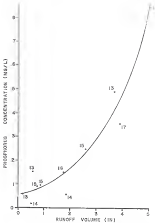


Figure 5 21 Total P Concentration versus Runoff Volume by Planning Unit for Wet and Dry Seasons

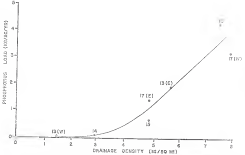


Figure 5.22. Total P Load versus Drainage Density in the Kissimmee River Basin

[illegible]
River Basin [illegible] D_d between [illegible]. Thus, the relationship between D_d [illegible] observed in other watersheds.

The [illegible] described a series of responses which [illegible] river basin as a function of the drainage [illegible] increased volumes of surface runoff, [illegible] and higher nutrient loadings are [illegible] ties in the Kissimmee River Basin. [illegible] more intensively [illegible], have potentially greater [illegible] loadings [illegible] applied to the land due to cattle [illegible] and fertilization. Thus, the fact that these areas produce higher export rates than more natural areas is not surprising.

Nutrient source loadings from cattle density and fertilizers were investigated in the Kissimmee River Basin in order to better evaluate the effect of drainage density. In general, the results show that nutrient loading depends on both the magnitude of source nutrients and associated drainage density. Figure 5.24 indicates this concept very nicely, especially for planning unit 15 where the nutrient source is relatively low but D_d is high and planning unit 16 where both parameters take on large values and produce heavy loading.

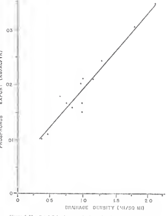


Figure 5-23. Total P Load versus Drainage Density in Canadian Watersheds (Adapted from Kirchner, 1974, p. 8)

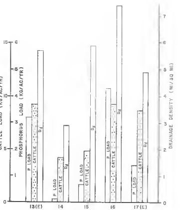


Figure 5 24 Influence of Nutrient Sources and D_d on Nutrient Loads

[illegible]

[illegible] standard [illegible] flo dplain. [illegible] agricultural and urban [illegible]ents have located along the lake shorelines, a demand f[illegible] of control for the upper basin lakes was expressed. The existing flood control project in the area uses structural controls and channelization to speed the flood waters through the chain of lakes, down the Kissimmee Canal, and into Lake Okeechobee.

A comparison of the flood hydrograph with and without the flood control project can be made by investigating the floods of 1953, 1960, and 1969. Figure 5.25 shows the monthly rainfall and daily streamflow for the Kissimmee River near Okeechobee, Florida (565-E) for [illegible] flood years. The 1969 flood occurred five years after the control works had begun operation and the other floods represent the response of the unchannelized river floodplain. Rainfall patterns are similar for the three floods with 1953 recording the highest rainfall amount. Table 5.11 characterizes the three events according to total flood time above 3000 cfs, recession time from peak flow to 3000 cfs, and total volume of flow. The 1953 and 1960 flood hydrographs are similar in all categories except for the actual shape of the curve. The recession for the 1953 event was slightly longer. The 1969 hydrograph is markedly different from the others and is

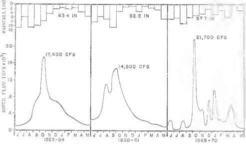


Figure 5.25. Recent Floods in the Kissimmee River Basin

[illegible]	[illegible]	[illegible] 3000 [illegible]	[illegible]	[illegible]
1953	[illegible]	[illegible]	[illegible]	[illegible]
1960	[illegible]	[illegible]	[illegible]	[illegible]
1969	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] total river length from about 40 miles to 50 miles.

This section develops a technique for predicting flood hydrographs discharged from the Kissimmee River Basin. The routing procedure uses input runoff from the HLAND model, and thus can simulate the response for any given land use pattern in the basin. The routing procedure can simulate the present C-38 channel system, or it can be altered to model the original meandering floodplain. In this way it is possible to determine whether the river channelization or the upland tributary drainage activities has caused the greatest change in the observed outflow hydrograph (Figure 5.25).

Description of the routing method

The total runoff for each planning unit predicted by HLAND, plus any inflows from upstream, can be routed through the main stem of the river by considering the governing momentum and continuity equations 2.15 and 2.16. It was shown in Chapter II that these equations can be simplified by considering a linear relationship between flow and storage. In a natural channel with overbank floodplains, the assumption of linearity may be approximately correct (Linsley et al., 1975), and the resulting storage equation is termed the Muskingum equation (see equation 2.17).

[illegible]

seasonal [illegible] primary [illegible]. Daily [illegible] used in order to complement the runoff calculations [illegible]

The Muskingum method is relatively simply in theory, using wedge and prism storage concepts to relate outflow to storage and inflow (Figure 5.26). During the advance of a flood wave, inflow always exceeds outflow, thus producing the wedge storage shown in Figure 5.26. Conversely, during the recession of the wave, outflow exceeds inflow resulting in a negative wedge storage. The wedge storage is represented by $KX(I - O)$ and the prism storage by KO. The total storage is, therefore

$$S = KO + KX(I - O) \tag{5.20}$$

where

S = storage

I = inflow

O = outflow

K = travel time parameter

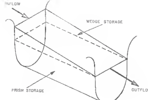
X = storage parameter

This is the Muskingum equation presented in Chapter II (equation 2-7), and may be written for two routing periods (1 and 2) as

$$S_2 - S_1 = K[X(I_2 - I_1) + (1 - X)(O_2 - O_1)] \tag{5.21}$$

Combining equation 5.21 with the continuity equation (equation 2.18) at the same two periods,

$$1/2(I_1 + I_2)\Delta t + 1/2(I_1 + I_2)\Delta t - 1/2(O_1 + O_2)\Delta t = S_2 - S_1 \tag{5.22}$$



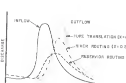


Figure 3.26. Schematic of Muskingum Routing Technique.

[illegible]

[illegible] (5.23)

[illegible] (5.24)

[illegible] (5.25)

[illegible] (5.26)

The P_1 [illegible] bution for two consecutive [illegible] ing periods (an [illegible] equation 2.18). The soluti[illegible] f equations 5.23 [illegible] compl[illegible] for consecutive segments of [illegible] river reach, [illegible] on the right hand side are known. [illegible] O_2 from one se[illegible] as I_2 [illegible] the next downstream segment. [illegible] ributary contribution[illegible] r[illegible] ruff are simply added in for each segment on a dail[illegible]

Values of K and X must be estimated for a part[illegible] segment. Graphical techniques and the analysis of obs[illegible] and outflow hydrographs are recommended. The value of K [illegible] tially the travel time in the reach in days. The value of X var[illegible] from 0.0 to 0.5 as a function of storage capacity in the ri[illegible], with the lower values related to greater storage. The effect of X [illegible] the routed hydrograph is depicted in the lower portion of [illegible] igure 5.26. Pure translation results when X = 0.5, and storage [illegible] reduces the peak for X = 0.0.

HLAND has been applied to the lower basin of the Kissimmee River south of Lake Kissimmee (Figure 5.10). Surface and subsurfa[illegible] runoff volumes are routed down the river to Lake Okeechobee using

[illegible]

[illegible] boundaries [illegible] inflows to the routing procedure. [illegible] applied on a daily basis, incorporating total runoff [illegible] planning unit, and ultimately providing the outflow hydrograph [illegible] Okeechobee.

By using present land use configurations (1972) and a series of daily rainfall patterns over the basin (1965-1970), the predicted outflow hydrograph from the Kissimmee River can be compared to measured streamflows at the gaging station near Okeechobee (S65-E). By adjusting storage (X) and travel time (K) parameters in the routing model to conform to the C-38 geometry, the HLAND model can be calibrated.

Hydrologic calibration of the model

The model HLAND was verified for the Kissimmee River Basin using present land use configurations and a series of daily rainfall patterns over the basin. HLAND calculates the contribution of total runoff to the river, which is then routed down the river to yield the predicted outflow hydrograph on a daily basis.

A series of calibration years, 1965-1970, was selected based on the availability of data and the fact that this sequence includes both drought and extreme flood conditions, which provides a good test of the accuracy of the model. A comparison of measured and predicted streamflows is depicted in Figure 3.27A at the gaging station near Okeechobee (S65-E). It can be seen that the model provides a generally accurate representation of the basin response during

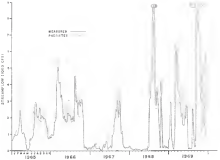


Figure 5 27A Measured and Predicted Hydrographs (1965-1970), Ki simee River

[illegible]

accurately predicting runoff [illegible] from each planning unit. A summary of flow data for selected planning units is presented in Table 5.12 in order to indicate the distribution of surface and subsurface runoff volumes. Total volumes of runoff for the basin are compared in Table 5.13.

In addition, HLAND was run for a 2-year period prior to channelization (1959-1960) using the 1958 level of land use for predicting runoff and the original meandering floodplain for routing the flows. Results are shown in Figure 5.28 for measured and predicted streamflows at S65-E. Based on calibration runs, the basin response seems to be much more sensitive to the land drainage characteristics than to the condition of the narrow river floodplain. Travel times were slower under the 1958 regime because upland marsh and slough retention provided additional storage capacity during the wet season. The present regime induces excess water into drainage canals at a faster rate, and thus yields increasing percentages of surface runoff compared to subsurface flows as shown in Figure 5.14.

The calibration procedure has revealed several interesting characteristics about the hydrologic response in the Kissimmee River Basin. These are listed below:

1) The basin has a marked wet season between the months of June and October associated with the majority of rainfall and streamflow volumes in the river.

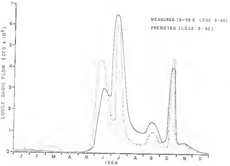


Figure 5 27B. Measured and Predicted Hydrographs (1968) Lower Ki[illegible]
River Basin

Table 5.12 Surface and Subsurface Runoff by Planning Unit (1967–1969)

Planning Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						1967 Runoff (10^3 ac-ft)							
13 (S)[a]	0.0	0.0	0.0	0.0	0.0	3.3	1.3	3.2	0.9	0.3	0.0	0.0	[illegible]
13 (G)[b]	0.7	3.7	1.8	0.0	0.0	2.9	6.9	9.7	6.6	4.7	0.0	2.5	[illegible]
16 (S)	0.0	5.1	0.1	0.0	0.0	5.0	4.4	0.0	19.0	13.0	0.0	0.0	[illegible]
16 (G)	0.3	3.8	2.4	0.0	0.0	2.6	4.0	2.5	3.5	4.4	1.8	2.2	[illegible]
						1968 Runoff							
13 (S)	0.0	0.0	0.0	0.0	5.6	23.0	14.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13 (G)	0.3	2.0	2.9	0.0	2.9	21.0	21.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (S)	0.0	0.0	0.0	0.0	3.5	44.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (G)	0.9	1.7	2.1	0.0	1.1	6.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
						1969 Runoff							
13 (S)	2.3	0.0	13.0	3.6	6.9	3.0	2.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13 (G)	6.2	3.3	14.0	7.9	14.0	8.8	8.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (S)	3.2	0.0	28.0	8.9	16.0	7.6	5.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 (G)	3.4	2.3	5.4	3.3	4.8	3.3	3.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a] Surface runoff

[b] Subsurface [illegible]

Table 5.13 Comparison of [illegible] (M) and [illegible] (P) Runoff Volumes (1967-1969)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	[illegible]
	Runoff Volumes (10^3 ac-ft)												
1967 (M)	12.0	14.4	10.5	6.1	23.9	29.3	33.2	104.5	145.8	102.6	15.4	15.[illegible]	[illegible]
1967 (P)	10.3	26.6	20.6	8.2	28.8	43.4	43.0	106.0	160.0	119.0	17.[illegible]	[illegible]	[illegible]
1968 (M)	14.0	11.7	10.4	6.1	12.1	209.7	415.1	229.2	177.2	[illegible]	[illegible]	[illegible]	[illegible]
1968 (P)	14.8	15.6	20.6	7.8	27.5	243.0	[illegible]92.0	186.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1969 (M)	89.6	28.[illegible]	219.1	164.[illegible]	106.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1969 (P)	88.7	[illegible]	[illegible]37.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

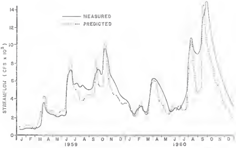


Figure 5.28. Measured and Predicted Hydrographs (1959-1960), Kissimmee River

1) [illegible]

2) [illegible]

3) [illegible]

4) [illegible] rather [illegible] C-38 [illegible] drainage [illegible] more volume and [illegible] before, [illegible] an increased hydrolo[illegible] overall

5) Planning units dominat[illegible] drainage canals tend to pr[illegible] more surface runoff than [illegible] units in a more natural state, while subsurface [illegible] are less under drained conditions.

Water quality in the river

Water quality monitoring in the Kissimmee River Basin was re-viewed in Chapter IV. Figure 5.29 shows the generally increasing trend for total phosphorus concentrations as one proceeds down stream. Nitrogen levels do not exhibit any significant spatial variation.

The section on drainage density in this chapter indicated a positive relationship between measured concentrations of total P, contributing to the river via tributary flow, and the drainage density index for that watershed. Similar relationships were obtained for total P loading (kg/ac/yr) and D_d, except that the loading rates increased exponentially downstream of S65-C (see Figure 5.22). The curve on Figure 5.29 exhibits the same type of increase below S65-C, indicating that the non-point source loading of total P from the tributary systems is the primary cause for the increase.

The concept of retention time, which has been a common theme in much of the previous discussion on storage and transport, also can be applied in the main channel of the river. The R factor used in the

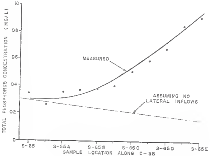


Figure 5.28. Water Quality (Total P) Along the River

[illegible] drographs at S65-E, a [illegible] 4.5 days was derived [illegible] the calibration of [illegible] the present C-38 configuration.

In order to estimate the potential for nutrient up[illegible] the river, equation 5.5 was applied to give an estimate of [illegible] concentration as a function of T. There is a problem in determ[illegible] the value of the decay constant k for the case of a river, but a commonly accepted value for nutrients in a river is 0.1 day^{-1} at 20° C. The resulting calculation for the ratio of outflow to inflow concentratio[illegible] is

$$C/C_o = e^{-kT} = 0.7 \qquad (5.27)$$

where

$k = 0.1 \text{ day}^{-1}$

$T = 3.5$ days

Thus, there is a potential for about 30 percent uptake (at 20° C) in the river under the present configuration. But for the section of the river below S65-C where most of the nutrient loading is generated, the retention time is reduced to about 1.0 day, and the revised calculation above results in only a 10 percent uptake potential.

The dashed line on Figure 5.29 indicates the uptake of nutrients which would occur in the river if lateral inflows of nutrients were completely curtailed. This result was obtained by solving a mass balance of inflow volumes and concentrations from Lake Kissimmee and

[illegible] previously

[illegible] the natural flood[illegible] the travel times were somewhat [illegible] the meandering pattern, but the analysis of hydrographs and the pre-channelization runs of HLAND indicate that travel times were no longer than about 9.0 days in the entire river. With the present upland drainage activities, especially downstream of S-65C, increased surface runoff volumes would tend to reduce the value of T if the natural floodplain still existed. Based on the above arguments, the potential upper limit for nutrient uptake in the critical lower two segments of the river was about 15 to 25 percent under the original floodplain regime, compared to 10 percent at the present.

The above simplified analysis of nutrient uptake potential indicates the relative range in values to be expected under both channelized and original floodplain regimes. For either case, the river and floodplain alone do not provide nearly the nutrient uptake which one might expect based on previous studies (Marshall et al., 1972). The main reason for this is the fact that the rapidly flowing river environment does not provide enough retention time for physical, biological, and chemical mechanisms to operate.

It has been mentioned that nutrient uptake requires relatively long retention times. This implies that the greatest potential would

[illegible]

lake areas. These re[illegible] in helping to delay sur[illegible]ting to [illegible], and in providing enough reten[illegible] nt uptake.

Lakes as Storage Control Units

A discussion of nutrient [illegible] has been presented in Chapter III, where limited [illegible] for several case studies of nutrient diversion. The most [illegible]t approach to lake restoration involves methods to limit [illegible] and/or sedimentation in lakes by controlling the problem at the source. However, in-lake schemes are available to accelerate nutrient outflow or prevent recycling. One such technique was applied to Lake Tohopekaliga (T[illegible]) in the upper Kissimmee River Basin which involved an experimental drawdown of the lake to slow the eutrophication process by consolidating loose sediments and detritus.

Lake Tohopekaliga is one of the largest lakes in the Kissimmee chain of lakes and currently supports a productive fishery. Inflows to the lake are from two primary tributaries, Shingle Creek and the C 31 canal. Outflow from the lake to Lakes Cypress and Hatchineha has been regulated by a control structure since 1964 (see Figure 4.1).

The [illegible] sewage [illegible] all [illegible] ding the [illegible] lation h[illegible] of game fis[illegible] bitat over the [illegible] years. [illegible] ary investigations in 1968 of [illegible] quality, sediment, algae, and fish populations, an extreme drawdown was recommended by the Florida Game and Fresh Water Fish Commission (GFC) to reduce or moderate the extent of habitat degradation. The drawdown was begun in February, 1971.

Lake level fluctuations and flood control

Before discussing the results of the drawdown, it is necessary to introduce the concept of lake level fluctuations. Prior to 1964 the level of Lake Tohopekaliga naturally varied from a low of 48.8 feet to a high of 59.4 feet (mean sea level), a range of 10.5 feet. The high water line is exceeded 15 percent of the time and the low water line 85 percent of the time, based on the stage duration curve in Figure 5.30A. The stage-area curve then determines the lake area for low, mean, and high water conditions (Figure 5.30B).

The Central and Southern Florida Flood Control District completed construction on a concrete lock and spillway at the lake outlet for flood control purposes. The present water regulation schedule permits a 2 foot fluctuation between 53 and 55 feet MSL. When lakes are regulated as in the Kissimmee River Basin, the zone of regulated fluctuation is usually reduced over natural conditions. Table 5.14 indicates the relative area of lake fluctuation for several Kissimmee

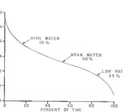


Figure 5.30A. Stage-Duration Curve for Lake Tohopekaliga (Bishop, 1967, p. 28)

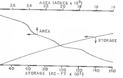


Figure 5.30B. Stage-Area and Volume Curves for Lake Tohopekaliga (Corps of Engineers, 1956, p. 55)

Table 5.14 Natural and Regulated Lake Fluctuation

Natural Water Level / Regulated Water Level	Lake Tohopekaliga Stage (ft msl)	Lake Tohopekaliga Area (1000 acres)	Lake Kissimmee Stage (ft msl)	Lake Kissimmee Area (1000 acres)	Lake Hatchineha Stage (ft msl)	Lake Hatchineha Area (1000 acres)
Natural Low Water	51.5	17.2	48.0	31.0	49.2	[illegible]
Natural Mean Water	53.5	20.7	50.5	35.0	51[illegible]	[illegible]
Natural High Water	55.5	23.3	52.5	40.5	53[illegible]	[illegible]
Zone of Natural Fluctuation	4.0	6.1	4.5	9.5	[illegible]	[illegible]
(Percent of Mean)		(29)		[illegible]		[illegible]
Regulated Low Water	53.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Regulated High Water	55.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Zone of Regulated Fluctuation	2.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(Percent of Mean)		[illegible]		[illegible]		[illegible]

[illegible]

[illegible]

[illegible] n under [illegible] regu[illegible] naturally [illegible] of 5 feet to [illegible] during the year. [illegible] schedules allow an absol[illegible] 3 feet to 55 feet [illegible] represents a significant r[illegible] area which [illegible] littoral zone previously [illegible] of marsh fringes [illegible] ndated all year. These [illegible] and [illegible] ish and wildlife, but also [illegible] buffer [illegible] and agricultural runoff wate[illegible] the uptake of nutrients by sub[illegible] and [illegible] Gleason, 1974). As these areas [illegible] d [illegible] waste [illegible] tive capacity is also reduced.

The fluctuations under natural conditions provided for flood storage in the large, flat buffer zones. Present regulation [illegible] maintain high pools in the dry season for recreation and irrig[illegible] and keep lower pools in the wet season for flood storage. Such flood control strategies induce agricultural and urban expansion with[illegible] lake basin. Drainage of these adjoining land areas increases the r[illegible] of runoff, which in turn increases the flood storage capacity which must be provided to protect existing flood plain developments. [illegible] point will soon be reached where natural lake capacity may be [illegible] and the conversion to a diked reservoir has traditionally been [illegible]

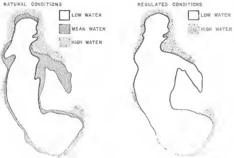


Figure 5.31 Zones of Natural and Regulated Fluctuations in Lake Tohopekal

[illegible]

[illegible] Figure [illegible] between [illegible] average, but [illegible]ctuation was almost [illegible] year 1960. The area of the lake fluctuated between 1[illegible] acres and 75,500 acres while the storage volume varied from 45,000 ac-ft to 125,000 ac-ft. For shallow lakes, small increases in stage can store tremendous volumes of water. Lake stages were regulated during the 1969 flood period.

In order to better understand the dynamics of the lake basin, hydrologic budgets have been prepared for the lake to provide an estimate of retention times and inflow and outflow volumes. The resulting balance of inflows, outflows, and changes in storage is shown in Table 5.15 for the year 1973, which represents an average year for rainfall. The monthly budget is based on applying the continuity equation to the lake basin (equation 2.4). Rainfall, evaporation, tributary inflows, surface runoff, and lake outflow were used to obtain an estimate of change in storage in the lake. Estimates of surface runoff were obtained by applying the WLAND model to the lake basin for present land use conditions. The calculated storage changes in the lake compare favorably with the observed values as shown in Table 5.15.

Retention time in the lake is defined as the total lake volume divided by the outflow of water. From the hydrologic budget, retention

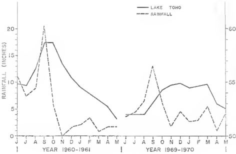


Figure 5 32 Effect of Regulation on Hydrologic Response

Table 5.15 [illegible]

1973	Jan	Feb	Mar	Apr	[illegible]	Jun	Jul	Aug	Sep	[illegible]	[illegible]	[illegible]
Precipitation[a] (P)	4.9	2.4	2.6	2.2	4.4	6.4	8.2	8.0	21.7	[illegible]	[illegible]	[illegible]
Evaporation[a] (E)	2.2	2.6	4.3	[illegible]	5.4	5.0	5.2	4.2	[illegible]	[illegible]	[illegible]	[illegible]
P-E	4.9	0.4	-3.5	[illegible]	-1.5	2.9	4.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shingle Creek	5.2	6.3	2.3	3.0	0.7	1.2	3.7	9.2	[illegible]	[illegible]	[illegible]	[illegible]
C-31	0.0	0.7	17.2	12.6	12.9	0.0	1.6	7.6	[illegible]	[illegible]	[illegible]	[illegible]
Runoff	11.0	3.2	0.1	0.0	1.9	2.4	5.6	3.6	17.0	[illegible]	[illegible]	[illegible]
Total Inflow	21.8	10.2	19.6	15.5	15.6	5.8	15.6	26.6	59.9	[illegible]	[illegible]	[illegible]
C-35	0.0	0.1	32.2	37.9	27.4	0.0	1.7	27.2	35.3	[illegible]	[illegible]	[illegible]
Total Outflow	0.0	0.6	33.7	[illegible]	28.9	0.0	1.7	27.2	[illegible]	[illegible]	[illegible]	[illegible]
Volume (S)	124.0	142.0	133.0	101.0	84.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Calculated ΔS	21.8	9.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lake Elevation[b]	54.1	55.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Observed ΔS	21.0	18.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note - all values in 10^3 ac-ft [illegible]

[a]Units of inches

[b]Units of feet (msl)

[illegible]

from about [illegible] .0 months during the [illegible] up to [illegible] months for the following dry season. During the drawdown experiment and drought conditions of 1971, the retention time exceeded 1.0 year since outflows from the lake were zero for most of the months during the experiment.

Based on the above hydrologic analysis, average retention time in the lake is assumed to be about 5.0 months, which implies that the lake turns over 2.4 times per year, on the average. It is difficult to say whether retention times have increased or decreased due to lake level regulation schedules. Because average storage capacity in the lake has been decreased while inflows have probably increased, one might conclude that average retention times have decreased since 1964. However, average outflows have probably decreased during the dry season due to the regulation schedule which maintains high pools. These conditions contribute to longer retention times for the dry season. During the wet season, outflows have probably increased while the average storage has been reduced for flood control, thus producing shorter retention times. In general, the value of retention time depends on the hydroperiod variation in the lake, and because wet season inflows and outflows represent the greater percentage of volume over the year, the average weighted retention time is reduced under the regulated condition. These changes in retention time due to

[illegible]

[illegible] sediment [illegible] by exposing [illegible] lake bottom to [illegible]. [illegible] habitat is [illegible] for bottom plant[illegible]. [illegible] of drawdown is expected to result in [illegible] total organic nitrogen, and volatile solids. [illegible] nitrates generally remain in the newly consolidated sediment [illegible]eral lakes in Florida have been studied in relation to the eff[illegible] [illegible]awdown (Fox and Brezonik, 1974), and consolidation of sediment [illegible] been observed

The drawdown sequence on Lake Toho proceeded from a high pool [illegible] feet in March, 1970 to a low pool of 52 feet in June. Following [illegible] months of drought the scheduled drawdown began in February, 1971 with a drop in elevation to 48 feet by June, exposing up to 50 percent of the lake bottom to the air. Reflooding occurred gradually until February, 1972 when the water level stood at the low pool stage of 52 feet. Complete results of the drawdown experiment such as the response of fish, vegetation, sediments, and algae are available (GFC, 1972, 1973). Water quality and nutrient loading effects are discussed below.

The general response to lowered water level and reduced volume was a gradual increase in concentration of most constituents and a reduction as reflooding progressed.

Table 5.16 shows the average water quality at three lake stations before, during, and after drawdown. The table demonstrates a concentration

Table 5.16. Averaged Water Quality of Lake Tohopekaliga Before, During, and After Drawdown

	Station 1			Station 2			Station		
	1970	1971	1972	1970	1971	1972	1970	1971	1972
Secchi (inches)	18.00	14.00	22.00	42.00	36.00	24.00	37.00	[illegible]	[illegible]
Field pH	7.50	7.90	7.30	5.40	8.20	8.70	6.60	[illegible]	[illegible]
Spec. cond.[a]	133.00	222.00	196.00	123.00	164.00	183.00	115.00	[illegible]	[illegible]
P Alk	0.00	1.00	0.00	0.00	1.00	4.00	0.00	[illegible]	[illegible]
T Alk	21.00	62.00	46.00	10.00	14.00	21.00	[illegible]	[illegible]	[illegible]
Sulphate	9.80	14.70	10.80	10.70	14.30	12.00	[illegible]	[illegible]	[illegible]
Turb. (unfilt.)[b]	85.00	217.00	85.00	49.00	40.00	68.00	[illegible]	[illegible]	[illegible]
Turb. (filt.)[b]	68.00	53.00	53.00	42.00	25.00	33.00	[illegible]	23.00	[illegible]
Ca	9.40	19.90	27.20	6.00	6.20	9.70	5.50	5.20	[illegible]
Mg	2.40	4.60	2.80	2.30	3.40	2.80	2.30	3.20	[illegible]
Na	9.40	14.50	15.30	9.10	17.80	17.80	9.00	27.00	[illegible]
K	2.60	4.10	2.60	2.30	3.10	2.80	2.10	[illegible]	[illegible]
NO_3-N	0.08	0.09	0.02	0.07	0.04	0.02	0.05	[illegible]	[illegible]
NH_3-N	0.09	0.20	0.11	0.04	0.02	0.10	0.03	[illegible]	[illegible]
TON	1.10	1.74	1.26	0.77	0.86	1.40	0.85	[illegible]	[illegible]
DON	0.72	0.83	0.87	0.69	0.60	1.00	0.61	0.58	[illegible]
PON	0.36	0.90	0.38	0.08	0.26	0.42	0.24	0.40	[illegible]
PO4 (ortho)	1.30	1.90	1.30	0.63	0.50	0.64	0.29	0.30	[illegible]
PO4 (total)	1.70	3.17	2.47	0.77	1.41	1.10	0.53	1.28	[illegible]

Note - data in milligrams per liter unless otherwise noted (From GFC, 1[illegible])

[a] Micromhos/cm

[b] Jackson turbidity units

[illegible]

[illegible] algal bl[illegible] declin[illegible] levels [illegible] tions

Reduction in NO_3-N reflects [illegible] increased productivity in the lake. [illegible] phosphate [illegible] at all stations compared to the drawdown period, but [illegible] the pre-drawdown concentrations

The major source of nutrients to the lake i[illegible] sewage effluent from five plants serving cities around the [illegible] of the lake. These are depicted as stations 5 through 9 in Figure 5 33. Agricultural runoff is a secondary source of nutrients to the lake Loading rates from the sewage treatment plants have been calculated by the GPC (1972)

The above information on nutrient sources combined with previous data on non-point sources allows a nutrient budget to be prepared for Lake Tohoe The nutrient budget approach is similar to the one used by Shannon and Brezonik (1972) Table 5.17 presents the results of the annual budget for nitrogen and phosphorus, where it can be seen that the sewage treatment plants are the major source of nutrients. Comparing the areal and volumetric loading rates to the critical loading rates in Table 3 1, it can be concluded that volumetric loading

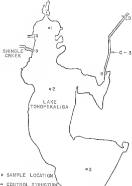


Figure 5 33 Water Quality Monitoring Stations for Lake Tohopekaliga

[illegible] algae

[illegible]	Nitrogen [illegible] g/yr)	Phosphorus (10^7 g/yr)
[illegible]	93	36.80
[illegible]	1.21	1.77
[illegible]	0.20	0.20
[illegible]10	1.29	2.70
Agric Land	6.87	1.45
Rainfall	3.47	2.72
Outflow	6.31	3.44
I-O	14.56	42.20
Areal Load	1.71 $g/m^2/yr$	4.96 $g/m^2/yr$
Volumetric Load	1.32 $g/m^3/yr$	3.80 $g/m^3/yr$

[illegible]

slow [illegible] feeds in [illegible]

[illegible] drawdown [illegible] water quality, it did succeed in establishing the major [illegible] to problem during the water quality monitoring program [illegible] (1972) feel that the treated effluent is the predominant [illegible] accelerating the degradation of Lake Toho at the present.

[illegible]ter quality and retention time

Further water quality monitoring efforts by the Flood [illegible] District during the past two years in the upper chain of [illegible] revealed an interesting response (Figure 5.34). The distr[illegible] total phosphate concentration declines significantly from [illegible] part of Lake Toho to the outflow from the lake, and then a much [illegible] decline occurs through Lakes Cypress, Hatchineha, and Kissimmee. These data suggest that uptake rates in Lake Toho are reducing the total P concentrations by approximately 85 percent by the time the water leaves the lake, depending on the season.

The concept of retention time T can be used to explain the observed decline in concentration. As in the case of the river, equation 5.5 can be applied to Lake Toho to estimate the reduction as a function of T and k, the first-order decay coefficient. Since C/C_o is known (Figure 5.34) and T is assumed to vary from 4.0 to 6.0 months, one can solve for the value of k at 20°C. These average values range from 0.02 day^{-1} for the wet season to 0.01 day^{-1} for the dry season

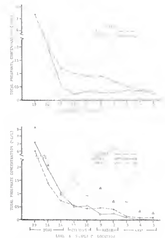


Figure 5.34 Water Quality (Total P) in the Upper Chain of Lakes

[illegible]

[illegible] n, because the nu[illegible] lake [illegible] other components of [illegible]. One poss[illegible] for the exponential [illegible] is in [illegible] process, with an initial [illegible] of nutrient [illegible] days and a final decay [illegible] months. [illegible] response would yield a value [illegible] day^{-1} for th[illegible] stage. Unfortunately, the frequ[illegible] collected by the FCD on Lake Toho does not allow a more [illegible] determination of k.

From a water quality standpoint, [illegible]t uptake depends on both the first-order decay coefficient and the retention time. Decay coefficients tend to increase with temperature, which affects biolo[illegible] and chemical activity. Retention times are shorter in the w[et] season when decay coefficients are at their peak, and longer in the dry season when uptake rates are at a minimum. Thus the hydrographic variation in the lake significantly influences the potential for nutrient uptake, especially in the wet season. These relationships imply that regulation schedules should be altered in order to retain water longer during the wet season, rather than drawing the lake down as rapidly as possible. These changes should also consider the needs of flood storage, so that a balance can be secured between objectives of water quality and flood control.

[illegible] compare favorably to a relationship [illegible] Kirchner and Dillon (1975). They [illegible] uptake to the areal water load [illegible] lake outflow divided by lake [illegible] areal water load is 2.64 m/yr on [illegible] average, and [illegible] to phosphorus uptake of 64 to 82 percent/yr from [illegible] The observed uptake is 85 percent.

Lake Toho, although receiving excessive loads of nutrients at the present time, is able to process a large percentage by biological or physical uptake. Water quality leaving the lake is much improved over water entering the northern side of the lakes, and other lakes in the chain further reduce total phosphorus concentration to an acceptable level prior to entry into the Kissimmee River.

It should be mentioned that this situation is subject to change if future developments around the lake should increase the loading and runoff rates such that retention times are reduced. If, for example, average wet season retention times were reduced from 4.0 to 2.0 months, then uptake would drop from 89 percent to 67 percent, assuming a constant first-order decay. Such a reduction would have a tremendous impact on water quality passing through the chain of lakes.

If the viability and habitat of Lake Toho are to be maintained, some form of nutrient diversion should be considered and implemented in the near future. Advanced waste treatment and spray irrigation of waste water are two possible alternatives which have been considered.

[illegible] provide more [illegible] by the TCD [illegible] quantity and water [illegible] wet season (Shih [illegible]).

[illegible] ation of marsh, [illegible] as well as outputs, indicate [illegible]. Flow measurements allow the [illegible] marsh for July and September [illegible] 5-60 days depending on the ratio [illegible] storage to [illegible]. In addition, depth and flow values are related through the Manning coefficient and slope (equation 2.13). For [illegible] slope, Manning's n increases with depth in the marsh as shown in Figure 5.35 from Shih and Hallett (1974). The Corps of Engineers (1954) relationship developed for sawgrass in the Everglades is plotted for comparison.

Using the Manning equation, it is possible to develop a stage-discharge curve for the marsh area, which is nonlinear as shown in Figure 5.36. While the stage and/or storage capacity in the marsh doubles from 1.0 to 2.0 feet, the outflow increases by a factor of 4.0. Thus, the detention time is reduced by approximately one half in this range

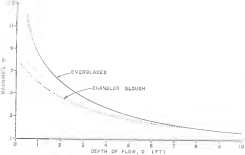


Figure 5.35 Variation of Manning's n with depth

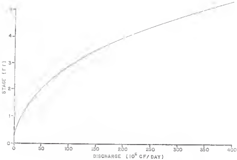


Figure 5 36 Stage-Discharge Relationship in the Marsh

[illegible]

[illegible] nutrient uptake.

[illegible]tion time [illegible]

[illegible] order to [illegible] estimate the response [illegible] a simple routing [illegible] from the WLAND model [illegible] through the 970 [illegible] the model is based on [illegible] curve depicted in [illegible] of the model are [illegible] (1975).

The [illegible] model was applied in order to determine the [illegible] of retention times in the marsh as a function of contributing land use in PU 16. Only 40 percent of the runoff is retained longer than 5 days under present land use conditions compared to 75 percent for 1958 land use. If the total marsh size in PU 16 is reduced by one fourth, then the runoff retained longer than 5 days is reduced to 10 percent for 1972 land use, and 20 percent for 1958 land use. These results indicate the significant influence of contributing runoff and relative marsh size to the predicted value of retention time.

The above conditions are analogous to the hydrograph response of pure translation compared to reservoir storage and attenuation.

[illegible] ge [illegible] (1976) [illegible] when the [illegible] in FL 36 [illegible] upon the ratio of drainage [illegible] It indicate that when this ratio [illegible] significantly reduced

These find[illegible] size of marsh storage [illegible] a profound [illegible] these areas are drained for impro[illegible] associated flood control is [illegible] which there is [illegible] [illegible] occurs when [illegible]

Retention time [illegible]

As discussed abo[illegible] up to 55 percent uptake of [illegible]. But this uptake is [illegible] many complex factors of biological growth and system response. A simple approach to the problem of predicting nutrient uptake was developed for river and lake systems based on the retention time, and this technique will be extended to the marsh area.

It is possible to apply equation 5-5 to solve for C/C_o if values of k and T can be determined. Based on the TCD water quality data in the marsh, nutrient uptake rates were calculated for two runoff events, with retention times of about 2.25 days and 4.5 days, respectively. The first event yielded 30 percent uptake, and the second yielded 55 percent

[illegible]

[illegible] [illegible] marsh [illegible] [illegible] potential [illegible] percent uptake [illegible] significant portion [illegible] when [illegible] water the [illegible] runoff.

[illegible] the [illegible] 14 has been [illegible] runoff volumes and [illegible] future [illegible] significant level [illegible] loading, as long as retention [illegible] long. An important issue to be addressed [illegible] involves the first flush effect. Studies will [illegible] build-up of nutrients through the dry season [illegible] the river with the first heavy rainfall [illegible] to be the case in Wisconsin marshes due to the spring [illegible]. It remains to be seen if such a condition applied in [illegible] River Basin. It should be noted that the heavy rains [illegible] retention times, in general, which further decrease the [illegible] for nutrient uptake at this time of the season.

Storage and Retention Time

... hydrologic-land use model HLAND calculates a water balance for each soil-land use complex in the basin, thus providing a continuous estimate of storage changes and runoff production from each planning unit. Source areas of runoff are identified, and characteristic retention times are calculated for different land use and drainage conditions, based on the detention storage constants. Base flow ... are incorporated as a function of soil moisture ...

[illegible]

[illegible] lower average retention times ([illegible]).

[illegible] range in values can be placed in [illegible] ing river, [illegible] and marsh retention times. The analysis [illegible] hydrograph at S65-E revealed a T value of 3.5 days for [illegible] River (C-38), which was used to calibrate HLAND. The hydr[illegible] udget on [illegible] vielded an average T value of 150 days, while [illegible] 3/0 [illegible] averaged about 5 days. The marsh valu[illegible] [illegible] comparable to the lake when considered on a per [illegible] [illegible]ly, the soil system is within this same order of magnitude. However, both the surface runoff and river system are dis[illegible] considerably smaller values of T, generally less than 5 days for a planning unit or the entire river. These results have significance in [illegible] with regard to nutrient transport in surface runoff and through the river system.

Nutrient source loadings are discussed in Chapter III for various land uses. Results are presented in Figures 3.2 and 3.2, showing that animal density on the land is an important determining factor. Table 5.4 presents the assumed relative nutrient loads for the Kissimmee River Basin

Transport and Retention Time

Retention time is an important concept in distinguishing modes of transport from the land, through the soil, and into marshes, lakes, and streams. Flood attenuation and the potential for nutrient loading

[illegible]

[illegible] in the [illegible]

Drainage Den[illegible]

The detai[illegible] along the lower river sy[illegible] presents planning unit [illegible] categorie[illegible] unit values [illegible] individual [illegible] range from 1 [illegible] associated wit[illegible] areas of ditc[illegible] (PL 16 and 17) have the [illegible] the average of [illegible]

From a hydrol[illegible] of total runoff is [illegible] about 30 percent on the up[illegible] age activities which have increa[illegible] ted by drainage density (Figure 5.15). [illegible] drainage dens[illegible] serves as an indicator for retention time for [illegible]lar land uses or planning units (Table 5 10)

Short retention times from intensively drained areas can contri bute to an increase in surface runoff as well as nutrient loading The concept of sediment delivery ratio and unit watershed size can be related to drainage density (Figure 5 17), and this leads to a further relationship between drainage density and nutrient loading Positive

[illegible] LAND for [illegible] nutrient [illegible] relat[illegible] [illegible]

In gener[illegible] runoff, higher [illegible] concentration[illegible] are associated [illegible] r levels of [illegible] However, [illegible] e.g., [illegible] drainage densit[illegible] [illegible] hydrologic and nutrient [illegible]

[illegible]r Routing Results

Flood control has lon[illegible] been [illegible] in the [illegible] River Basin. Figure 5.25 shows the dail[illegible] response [illegible] channelized (1969) and original floodplain [illegible]nditions. The basin has a marked wet season (June to October) when [illegible] of the rainfall and streamflow occurs. Remaining months of the year are dominated by low flows. The 1969 hydrograph is markedly different from the [illegible] is characteristic of a developed drainage system with higher peak flows and travel times.

The output from MLAND for each planning unit is routed dow[illegible] river to yield the predicted outflow hydrographs. A series of [illegible] years are compared to measured values at S65-E in Figure [illegible]

[illegible] d subsurface runoff [illegible] s for 13 2 land use [illegible], Unit 16, characterized by high drainage density, [illegible] ides 70 per[illegible] surface runoff compared to 30 percent for PU 13. [illegible] total volumes of runoff do not appear to increase under future land use patterns (2020), the percentage of total runoff which is via surface routes increases with the drainage density. For example, surface runoff in PU 13 increases from 30 percent for present land use to about 60 percent under future conditions, primarily due to drainage activities.

Based on the calibration runs, the basin response seems to be much more sensitive to the land drainage characteristics than to the condition of the narrow floodplain. Travel times were slower under the 1958 regime because upland marsh and slough retention provided storage capacity to delay runoff. The present regime induces excess water into drainage canals at a faster rate, thus creating an increased hydrologic response in the river channel.

The routing technique used above incorporates a travel time, or retention time, of the Kissimmee River. A value of 3.5 days was used for the present regime, with a possible upper limit of 9.0 days for the original floodplain. These short retention times result in a 30 percent uptake potential for nutrients in the entire river, compared to 10 percent for the critical section below S65-C where most of the loading is generated. Figure 5.29 shows the generally increasing

[illegible]

[illegible] g and nutrient [illegible] floodplain alone do not p[illegible] take due to the short retention time. In addition, th[illegible] water [illegible]tering the upstream end of C-38 is of fairly good quality, and degrades rapidly below S65-C due to agricultural loading

Since nutrient uptake requires relatively long retention times, the greatest potential for uptake would occur in lakes and marsh storage areas. These areas provide a double service in helping to delay surface runoff from contributing to flood flows also

Lake and Marsh Studies

The analysis of Lake Tohe for flood control and nutrient uptake yields some interesting results. The present lake level regulation schedule has resulted in a decrease in fluctuation from 29 to 11 percent of the total lake area. Large areas of marsh fringes formerly in the littoral zone are now inundated all year.

Based on the hydrologic budget on the lake, average retention time in the lake varies from 4.0 to 6.0 months in wet and dry seasons respectively. During extreme floods, the value can drop as low as 1.0 month. The value of retention time depends on the hydrological variation in the lake, and the average value is generally reduced under regulated conditions due to higher outflows and lower storage, in the wet season

the lake (Figure 5.34). The uptake depends on [illegible] decay coefficient and the retention time. [illegible] in the wet season when decay coefficients are [illegible] longer in the dry season when uptake rates are [illegible] implies that regulation schedules should be altered [illegible] during the wet season for more uptake, while also [illegible] needs of flood storage. If future developments [illegible] tion in retention times from 4.0 to 2.0 months [illegible] drop from 89 percent to 67 percent, which would [illegible] impact on water quality. In the long run, some [illegible] diversion should be considered and implemented [illegible] the viability and habitat of Lake Toho.

The study of a marsh area in PU 16 reveals their [illegible] flood attenuation and nutrient uptake. Retention times [illegible] 3.0 to 5.0 days and provide from 30 to 55 percent uptake of total [illegible] These results depend to a large extent on contributing drainage ar[illegible] and marsh size. Flood attenuation is significantly reduced when the percent area in lakes and swamps is less than 15 percent (Figure 2.1 [illegible] or when the ratio of drainage area to marsh area exceeds about 25:1 in PU 16. As marshes are drained for improved pasture and other uses associated potential for flood attenuation and nutrient uptake is also reduced.

The distribution of retention times in the present marsh area was determined by a routing model, and results yielded a 5 day [illegible]

[illegible] During [illegible] the first flush of [illegible] can be delayed [illegible]

Summary [illegible]

The study of the Kissimmee River Basin [illegible] importance of managing upland drainage and [illegible] to control quantity and quality of runoff [illegible] drainage activities have led to increased volumes [illegible] runoff as well as [illegible] nutrient loads. It has been [illegible] storage in [illegible], pond and lake areas provide [illegible] necessary retention time for [illegible] attenuation and nutrient uptake.

The Kissimmee River Basin should be managed in order to maximize retention time and keep water on the land as long as possible through the use of available marsh storage areas and small check dams in heavily drained areas. Alterations of the river floodplain will have little effect except for increasing habitat for fish and wildlife. Nutrient uptake potential is comparatively low in the river channel compared to marsh and lake areas.

Lower portions of the Kissimmee River Basin have generally been overdrained. In agricultural areas, adverse drainage effects may be minimized by routing runoff through man-made or marsh storage areas, and on-site storage will help to provide harmonious conditions between both agricultural development and natural land in the basin.

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Biographical Sketch

Philip Bruce Bedient was born January 13, 1948, in Greenbrook Township, New Jersey. He graduated from Sarasota High School in June, 1965. After attending the University of Mississippi for one year, he transferred to the University of Florida in 1967 and received a Bachelor of Science with High Honors in Physics in June, 1969.

He continued in the Department of Physics as a graduate student before transferring to the Department of Environmental Engineering at the University of Florida in September, 1970. He worked until December, 1971, as a graduate student taking courses and pursuing research toward the degree of Master of Science with a major in Environmental Engineering which was conferred in March, 1972.

After receiving an educational delay from the U.S. Army, he stayed on in the department as a graduate assistant. He completed work on the Upper St. Johns River Basin Study prior to the completion of the present study on the Kissimmee River Basin, Florida. He will receive the Doctor of Philosophy in Environmental Engineering in June, 1975.

After serving three months with the U.S. Army, he will assume a faculty position as Assistant Professor, Department of Environmental Science and Engineering at Rice University, Houston, Texas.

Philip Bruce Bedient is married to the former Cynthia Marie Cont[illegible]. He is a member of Phi Beta Kappa.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Wayne C. Huber
Assistant Professor
Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. James P. Heaney
Assistant Professor
Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Howard T. Odum
Graduate Research Professor
Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. John J. Ewel
Assistant Professor of Botany

This dissertation was submitted to the Dean of the College of Engineering and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

April, 1975

Dean, College of Engineering

Dean, Graduate School